Estimating Health Benefits when Behaviors are Endogenous: A Case of Indoor Air Pollution in Rural Nepal

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

A majority of rural households in developing countries still use solid fuels for cooking. Many studies show linkages between the indoor air pollution from solid fuels with respiratory health problems. These estimates, however, suffer from an endogeneity bias arising from the effects of health conditions on fuel choice. This study estimates the effects of indoor air pollution on respiratory health after adjusting for endogenous health behaviors. Our study, which includes measurements on indoor air pollution, is based on a detailed survey of 600 rural households from Syangja and Chitwan districts of Nepal. We employ instrumental variable probit regressions to find the effects of pollution-reducing interventions on chronic bronchitis, asthma and acute respiratory infections. The estimates with the instrumental variable approach are found to be larger than those that do not correct for endogeneity. Improved cook stoves and biogas are found to reduce respiratory diseases. We also estimate household shadow values for chronic bronchitis, asthma and acute respiratory infections using the cost of illness method. We estimate the annual reduction in health costs per intervention of stove to be Rs 1,217 and that of biogas to be Rs 647. The health benefits from improved stoves are many times higher than the cost while the health benefits from biogas plant are nearly equal to its cost. We, however, do not include other benefits of the interventions like energy efficiency, forest conservation and reduction in carbon emissions. The comparison between annual health benefits and costs shows that there is no clear reason for not buying the interventions.

Keywords: Indoor air pollution, Biogas, Chronic bronchitis, Asthma, Acute respiratory infections, Instrumental variable probit.

JEL Classification: Q42, I12.

Estimating Health Benefits when Behaviors are Endogenous: A Case of Indoor Air Pollution in Rural Nepal

Krishna Prasad Pant

1. Introduction

Many rural households in low-income countries use traditional biomass fuels for cooking, which is a major source of indoor air pollution (IAP) and related illnesses. Approximately half the world's population, which includes up to 90 percent of rural households in developing countries, still relies on unprocessed biomass fuels in the form of wood, dung and crop residues (World Resources Institute, UNEP, UNDP, World Bank, 1998). Pollutants from biomass fuel combustion for cooking are the main source of IAP and a primary cause of respiratory ill health among rural people, particularly among those who cook food. Empirical studies consistently report significant direct relationships between exposure to IAP and respiratory illnesses (Pandey, 1984; Pandey, *et al.,* 1989; Smith, 2000).

Studies show that over 89 percent of total energy use in Nepal comes from traditional fuels (ADB, 2003). The exposure to IAP, especially to particulate matter, from the combustion of biomass fuels (wood, charcoal, dung and agricultural residues) has been cited as a causal agent of respiratory diseases (Chen, *et al.*, 1990). Although charcoal, dung and agricultural residues are in limited use in Nepal, 66 percent of households use wood as the main fuel for cooking. The use of modern fuels in contrast is rather limited. Only 13 percent of households use kerosene while eight percent use liquid petroleum gas (LPG). Households using biogas as the main fuel is less than two percent (CBS, 2002).

In the past decade, the literature on IAP and health has grown rapidly, including analyses of the magnitude of the problem, and the physical impacts of interventions (Larson and Rosen, 2002). But estimates of the effects of IAP on respiratory illness obtained from the literature suffer from problems of endogeneity. Although effects of IAP on respiratory health are discussed in several studies, most ignore the effect of health conditions on stove and fuel choice. Ignoring this endogeneity leads to biased measures of the effects of behavior on health (Briscoe *et al.*, 1990). If we use an ordinary least square (OLS) to estimate the effects of air pollution on health, the error term is correlated with explanatory variable air pollution. When the level of pollution is high, the error term is likely to be negative; when the pollution level is low the error term is positive. The correlation of the explanatory variable with the error term violates the basic assumption of the OLS. Therefore, not only does exposure to pollution affects health but health problems affect the exposure leading to a problem of endogeniety. In such case of circularity, single equation estimate results in a simultaneity bias with inefficient estimates.

On the policy front, IAP is inextricably linked to poverty. It is the poor who both rely on lower-grade fuels and have the least access to clean technologies for cooking and heating (Bruce, *et al.,* 2000). Therefore, reducing IAP can contribute to the Millennium Development Goals of poverty reduction by reducing health costs and making the people better off. Moreover, many studies emphasize that poor women and children are at greatest risk from the health effects of IAP (Boy, *et al.*, 2000). However there has been little analysis to date of the reasons for low household-level demand for IAP reducing interventions. Public health officials, researchers and program implementers working in the area of IAP abatement, therefore, need to understand the health benefits of IAP reducing interventions. Though the literature on IAP and health has grown rapidly, it is still not clear why acceptance and adoption of improved technologies that reduce IAP are still low in the rural areas of developing countries.

This research aims to estimate the precise effects of IAP on child and adult respiratory health after adjusting for the simultaneity bias created by the problem of endogeniety. The specific objectives of this study are to: a) find the factors, including interventions, affecting the level of particulate pollution in the kitchen; b) estimate the marginal effects of indoor air pollution variables on respiratory health outcomes of adults and children; c) estimate the household's shadow prices for changes in child and adult health; and d) estimate the marginal willingness to pay for the interventions that reduce respiratory health problems. The data for this study comes from a survey of 600 households selected randomly from six Village Development Committees from Central Nepal.

The next section deals with health costs of indoor air pollution. The third section is devoted to the description of the study area. The methodology of the study is discussed in detail in section four. The section five presents the results and discussion including particulate pollution, determinants of health symptoms and health benefits of intervention. Section six concludes.

2. Health Costs of Indoor Air Pollution

A major shortcoming in the literature on air pollution and the subsequent health hazards has been its focus on outdoor air pollution. Remarkably few studies have measured IAP (Pearce, 1996). World Health Organization however recognizes that human exposure to a number of important indoor air pollutants is much larger than those created by outdoor pollution (WHO, 1997). If we were to add up the total population of the developing world and express it as person hours, 70 percent of all person hours are spent indoors (Smith, 1988). Though the research on exposure to indoor smoke and its impacts on respiratory diseases in developing countries began in the 1960s and '70s in India, Nigeria, and Papua New Guinea (Ezzati and Kammen, 2002), the evidence for causal links between IAP and several diseases is still accumulating.

Poor people use biomass fuel for cooking because they are cheaper than modern fuels and are generally easily accessible. But the health costs can be high – a point that is generally not understood or ignored by the less educated rural poor to whom the linkages between their diseased condition and the type of stove they use or the fuels they burn are not clearly visible. The indoor use of biomass fuels leads to levels of IAP many times higher than international ambient air quality standards that expose poor women and children on a daily basis to a major public health hazard (von Schirnding, *et al.*, 2000). The biomass contains a large number of pollutants and known health hazards, including particulate matter (PM), carbon monoxide (CO), nitrogen dioxide, formaldehyde, and polycyclic organic matter, such as benzoapyrene, a carcinogen (Ezzati and Kammen, 2002). Burning a kilogram of wood in a new wood stove will produce about 130 grams of carbon monoxide, 51 grams of hydrocarbons (including up to 10 grams of carcinogenic benzene), 21 grams of fine particulates, and about 0.3 grams of the highly carcinogenic polycyclic organic hydrocarbons (EPA, 1986; Larson and Koenig, 1993). Wood burning also produces 10 to 167 milligrams of highly carcinogenic dioxins per kilogram of fuel burning (Abelson, 1994). When exposed, these pollutants are found to cause respiratory diseases to the individuals.

Chronic obstructive pulmonary disease (COPD) is a severe respiratory health problem. It is characterized by abnormalities in the lungs which make it difficult to exhale normally. Generally, two distinct diseases are involved in this case: emphysema and chronic bronchitis. Emphysema and chronic bronchitis cause excessive inflammatory processes that eventually lead to abnormalities in lung structure that permanently obstruct airflow (hence the term "chronic obstructive"). A recent study shows that adults with asthma are 12 times more likely to develop COPD than those who do not have the condition (Silva *et al.* 2004).

Similarly, acute respiratory infection (ARI) is another severe respiratory problem typically common among the children. It is the single most important cause of mortality in children under five years of age, accounting for around 2 million deaths annually in this age group. Various studies in developing countries have reported on the association between exposure to indoor air pollution and acute lower respiratory infections (Kossove, 1982; Campbell, *et al.*, 1989; Collings, *et al.*, 1990; Armstrong and Campbell 1991). In rural Nepal many such patients are not diagnosed and treated properly. Data on COPD and ARI are not readily available for the study and the challenging data gap is met by the household survey. More challenging is the adoption of the intervention to reduce the root cause of such diseases – the pollutant.

Studies show that the interventions for reducing IAP save health costs to people affected. Yelin *et al.,* (2002) estimate the direct cost of all respiratory diseases at $45 billion in the US (in 1996 prices). They show that healthcare expenditure on behalf of persons with respiratory conditions has a substantial impact on the nation's economy and that the increment specifically attributable to these conditions raises total expenditure among persons with respiratory conditions. The intervention also saves lives. Smith (2000) makes a conservative estimate that nearly half a million premature deaths annually can be attributed to the use of biomass fuels.

The available literature has not arrived at a consensus on the ways to either mitigate or prevent IAP when it comes to poor rural households in developing countries. On one hand, recent reports from Bangladesh (Dasgupta *et al.*, 2004, 2006) link the level of IAP with wall and roof permeability as well as the location of the kitchen and its openness to other rooms in the house. They find that the construction of walls and roofs have significant effects on IAP concentration. However, they also find that different sources of biomass fuel contribute very little towards explaining differences in measured average IAP. They conclude therefore that fuel choice is less important than ventilation factors when it comes to explaining variation in IAP among poor households. They further argue that while ventilation changes are inexpensive, lack of awareness among rural dwellers becomes the primary limiting factor in preventing the problem of IAP.

However, using Bangladesh as a case study, Pitt *et al.* (2005), conclude that improving ventilation by increasing the permeability of roofs or walls has no significant effect on the health outcomes. They conclude that proximity to the stove is the major factor in explaining health effects. They argue that household decisions regarding division of labour along gender lines lead to different levels of exposure of individual family members to IAP. These findings might lead us to conclude that avoiding exposure to the stove could be one of the major preventive measures. The household can decide to spare a particular member by allocating other jobs to him or her. However, sparing an individual member of the household cannot help a household as such since someone has to be assigned the task of preparing food.

It should be however noted that attempts to prevent exposure to pollution by either making the wall or roof of the kitchen permeable or by switching the stoves or fuels in use can only be endogenous if the households make such adjustments with the express intention of reducing IAP. The reallocation of household labour in order to mitigate the problem of respiratory illness due to IAP is also endogenous if the decision is made on the basis of the knowledge that exposure to pollution was the cause. Such decisions, dependent on past or current health conditions or perceived future problems create circularity from an analytical perspective. Briscoe *et al.* (1990) argue that the estimates become biased if such problems of endogeneity are ignored. Unbiased and reliable estimates of health benefits are thus required in order to assist rural people to make sound decisions.

3. Study Area

Our study employs primary data generated from a sample survey and pollution monitoring observations in the rural areas of central Nepal (see Map 1).[1] Over 81 percent of the households in this area are rural dwellers (CBS, 2002). Although fuel use statistics are not available separately for the rural and urban areas, the dependency on solid fuels is higher in rural areas. People use kerosene mainly for lighting purposes in areas that do not have access to electricity.[2] Because of unavailability, switching to LPG and electricity are not the options in rural areas.

Until recently, the health effects of IAP due to burning of biomass cooking fuels have not been known in the area. Some interventions like improved cooking stoves (ICS) and biogas plants are sparse in their impact and reach. Though the intensity of such interventions is higher in the central part of the country, coverage is still very low benefiting only about two percent of the population. Moreover, ICS and biogas are aimed particularly at reducing fuel-wood consumption.

Two districts, Syangja from the hill area and Chitwan from the plains, were selected purposively for the study. The Village Development Committees (VDCs), the smallest administrative units, in each district were ranked on the basis of the intensity of ICS and biogas plants. The intensity of ICS and biogas in each VDC was estimated by taking the ratio of adopter households that have completed one year of adoption[3] to the total number of households. From the VDCs thus ranked, we selected three sample VDCs from the first 12 VDCs by using systematic sampling with a random start.[4] That is, we selected one VDC randomly from the first four while from then onwards every fourth VDC was selected to make a sample of three VDCs in each district. Thus the sampling is unequal probability sampling giving more weight to higher intensity areas than to the lower intensity areas. The rationale behind this sampling scheme is to develop a sample of households with a sufficiently large number of interventions, mainly ICS and biogas for statistical analysis.[5]

A list of the households obtained from the records of the selected VDCs forms the sampling frame. The population of Nepal living in the hills (including mountains) is about fifty percent; the

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[1] For purposes of development administration, Nepal is divided into five development regions, namely Eastern, Central, Western, Mid-western and Far-western.

[2] Nearly 63 percent of the households in Nepal are not yet supplied with electricity (CBS, 2004).

[3] Interventions adopted in the recent months may not be enough to exhibit the effects on respiratory health.

[4] Syangja district comprises of 60 VDCs and Chitwan district 37 VDCs. In addition, each district has two municipalities. These are not included in the sampling frame.

[5] Nepal Living Standard Survey (2003/04) shows that only two percent households in Nepal have a biogas plant while two percent have improved cooking stoves.

rest live in the plains. Accordingly, we divided the sample equally for the hills (300 households) and the plains (300 households). We then allocated the sample households in each district to three select VDCs[6] based on the probability proportionate to the number of households. From the sampling frame for each select VDC, we selected the required number of sample households and one-fourth replacement households.[7] In the survey, the actual number of replacement households is less than two percent.

We conducted the household survey using a structured pre-tested questionnaire. The questionnaire included modules on stove and fuel, family and respiratory diseases, costs of illness and household income (please see Annex I for details). It was administered by a team of trained enumerators. In rural Nepal, many diseases go untreated or at least not properly diagnosed. Consequently, we undertook a survey of symptoms - in order to identify cases of COPD, for instance, we surveyed the symptoms of chronic bronchitis and asthma. Similarly, we surveyed the appearance of the symptoms of ARI when it comes to the children.

We selected a sub-sample of 99 households for pollution monitoring in the kitchen. The procedure adopted was the random selection of one out of the three sample VDCs for each district.[8] Similarly, the selection of the monitored households out of the sample households was random. PM and CO are major pollutants in the biomass burning kitchen. As the effect of CO is short lived and that of PM is cumulative, many studies focus on the latter. Our study monitored the PM_{10} level[9] in the kitchen using the Laser Dust Monitor (LD–1). The LD-1 measures the intensity of the laser beam scattered by the dust particles of specific size. The device is run for 10 minutes for each reading. Investigators took two readings from the kitchen of each sample household – one during cooking and another during no cooking. For each reading, the researchers first converted the counts obtained for 10 minutes into count per minute (CPM); they then converted the CPM to a microgram per meter cube of air (µg/m³) multiplying by a conversion factor (k= 9.192) developed by Yadav *et al.* (2004) in similar situations by running Laser Dust Monitor and the High Volume Air Sampler side by side.

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6 The sample VDCs are Setidobhan (81 sample households), Sworek (125 households) and Tindobate (94 households) from Syangja district and Pithuwa (105 households), Gitanagar (125 household) and Shivnagar (70 household) from Chitwan district.

7 The number of households in the VDCs of Syangja district is found to be smaller than those in the VDCs of Chitwan district. In Syangja district, we select one household randomly from the first nine households while every ninth household is selected thereafter. In order to develop the 25 percent replacement households, we selected the first household randomly while every 36th household is selected thereafter. Similarly, from the register maintained by the VDCs in Chitwan district, we selected one household randomly from the first 20 households, while every 20th household from it is selected thereafter. In order to develop the 25 percent replacement households, after the first household is selected every 80th household from it is selected thereafter.

8 The sub-sample for monitoring includes 50 households from Sworek in Syangja district and 49 households from Gitanagar in Chitwan.

9 Particulate matters of size 10 micron or less (PM10) are more damaging to health than the particulate matter of larger size

4. Methods

We use households as the unit of analysis. With given exogenous income and time, households attempt to maximize their utility with consumption, leisure and fuel attributes. Every fuel carries a cost to the household. Some fuels have direct costs, others have indirect costs, while some others have both in different proportions. Electricity and petroleum fuels have direct costs like startup costs and consumption-based tariffs. Biomass fuels collected or produced by the household itself carry the opportunity cost of labour and land. The time and budget constraints implicitly capture these opportunity costs. When the households operate in fuel markets, the price is determined by the market price. For non-market participants, the price of biomass is the opportunity cost of collection labour and the indirect health costs if that is known to them. Our study focuses on estimating these indirect health costs.

We begin with the notion of household welfare represented by an indirect utility function, where utility is derived from the consumption of various goods and services and leisure. As the health of family members is affected negatively by polluting fuels like fuelwood, it is necessary to consider an expanded form of the household utility function that includes health-related variables. Households can be viewed as choosing a combination of fuels that maximize their utility from cooking to fuel efficiency and health given full information, budget and other resource constraints. But, health costs being indirect, it is hard to believe that the households have full information. The study attempts to generate information that will be helpful in the reconsideration of benefits and costs by households in the hope that it will in turn lead to an increase in the adoption of pollution-reducing interventions and household utility.

Given our interest in understanding the health impacts of IAP and household's demand for less polluting technology, the household utility maximization allows us to test the following alternative hypotheses:

a) Improved stove technology reduces indoor air pollution;
b) Switching to clean fuel reduces the level of particulate pollution in the kitchen;
c) Adoption of improved stove and clean fuel affect positively the respiratory health of adults and children;
d) The shadow prices of households for changes in child and adult health is positive;
e) Health benefits of major interventions are larger than their market price.

For testing the first and second hypotheses, we estimate a pollution production function, whereas for testing the third one we estimate a health production function. The last two hypotheses are tested using cost of illness estimates.

4.1 Determinants of Indoor Air Pollution

There are three practical strategies through which to figure out which set of activities and behaviors are associated with IAP generation. First, we summarize the data to see if a sufficient number of people engage in an activity. Next, we note whether there is some variation as well as correlation between activities. For example, since almost everyone uses dry wood and/or breaks firewood into small pieces before cooking, this reduces the likelihood that we will be able to find out how such behaviors influence IAP in this sample. Third, based on the understanding we have from the first two strategies, we estimate a pollution production function.

After making a short list of behaviors/choices, which include fuel choice, cooking technology, kitchen characteristics, and behaviors during cooking (breaking into small pieces, using dry wood and kerosene to start the fire, etc.), we followed the second strategy and dropped some of these variables from our analyses. Then, for the data set of 99 households (for whom PM_{10} was measured), we regressed the measured PM_{10} on the short-listed behaviors in order to identify which choices significantly affect IAP (all else being equal).

We estimated a log-linear production function for IAP. We then tested for the problems of omitted variables, heteroskedasticity and multicollinearity in order to gauze the reliability of the estimates.

We specify the pollution production function as follows:

$$\ln(PM10_j) = \alpha + \beta_1 S_j + \beta_2 F_j + \beta_3 K_j + \beta_4 t_j + e_j \qquad (1)$$

Where, *ln* (PM_{10j}) is the natural log of the level of PM_{10} measured in the kitchen in household *j*; S_j is the type of stove in the household *j*, *Fj* is a vector of fuel used in the household *j*, K_j is a vector of kitchen structures in household *j*, t_j is the time spent (hours/day) for cooking in household *j*, e_j is the error term; and $\hat{a}_1$, $\hat{a}_2$, are coefficient vectors and ±, $\hat{a}_3$ and $\hat{a}_4$ are the coefficients to be estimated.

4.2 Health Benefits of Interventions

In order to estimate the individual health effects of pollution variables, we regress individual health outcomes on pollution variables and individual characteristics. This model includes the fixed effects in terms of geographical area.

We estimate a probit regression with a dichotomous dependent variable (y = 1 when symptoms exist and y = 0 when there are no disease symptoms). This model is derived from the normal cumulative distribution function (CDF) (Gujarati, 2003).

$$\Pr(y_i = 1) = F\,(x_i b) \qquad (2)$$

Here b is a parameter vector to be estimated, and F is the normal cumulative distribution function. The term 'xb' is the probit score or utility index. Since 'xb' has a normal distribution, the probit coefficients are tested with the Z test (Gujarati, 2003).

We assess the negative impacts of indoor air pollution on respiratory health outcomes for chronic bronchitis and asthma among 2,723 individuals and for the ARI among 301 children. In rural areas of Nepal, it is practically difficult to analyze cost of illness on the basis of medically identified cases of such diseases from the household samples because many diseases go untreated or at least not properly diagnosed. Hence, the visible symptoms of these diseases are surveyed for the purpose. Symptoms of chronic cough and hemoptysis are taken as the indicators for the presence of chronic bronchitis and shortness of breath or dyspnea as the indicators of asthma. The ARI symptoms are assessed for children aged five years and less. The explanatory variables included are cooking technology and fuel, and personal characteristics such as age and gender.

We estimate the following probit equation as the health function of pollution exposure, conditional on individual and household characteristics:

$$\Pr(Hij = 1) = \alpha + \beta_1 W_j + \beta_2 A_{ij} + \beta_3 G_j + e_{ij} \qquad (3)$$

Where, H_{ij} is the incidence of any respiratory disease symptom for person *i* in household *j*; W_j is a vector of smoke averting activities (stove and fuels) adopted by household *j* that are endogenous; A_{ij} is a vector of person-specific attributes (age, gender) that are exogenous; G_j is a geographical characteristic (hill or plain) that is exogenous; e_{ij} is the error term; $\hat{a}_1$, $\hat{a}_2$ and $\hat{a}_3$ are the vectors of coefficients to be estimated.

We call *W* the pollution variables not because they measure IAP (as in PM_{10}) but because they are the best proxy, given the nested sampling for PM_{10} in 99 (and not 501) households. Pollution variables such as fuel and stove are more visible and meaningful to discuss with rural households than the actual measure of pollution level that the scientific community prefers.

4.3 Instrumentation of Endogenous Variables

First we identify exogenous variables, such as, age, sex, and geographical area of residence that may affect the health outcomes. Then we identify the potentially endogenous variables that affect health and are also likely to be affected from health-related household decisions. The endogenous variables identified are ICS plus heaters, biogas, LPG and fuel wood. These endogenous variables are instrumented using a set of instruments that are discussed below.

Identification of valid instruments requires imagination, diligence, and sophistication (Murray, 2006). We short-listed all possible candidate instruments first and tested their association to the health outcomes based on the validity and strength criteria discussed above. We identified as valid instruments those variables that do not have correlation with the health outcomes (see details in Annex VII). Similarly, we measured the associations of the candidate instruments with the instrumented endogenous variables to find the strength of the instruments. We intuitively selected probable candidates for instrumental variables like households characteristics (sex ratio and access to credit), land holding (irrigated land, non-irrigated land and total land), farm production (production of rice, maize), the location variable (distance to the market), price variables (price of LPG, fuelwood, biogas, ICS, subsidy received for biogas), and income variables (salary income, non-agriculture income, income from crops, income from livestock and total agriculture income, ratio of non-agriculture income to total income). We tested each of these candidates for their strengths (using zero-order correlation) to work as instruments for endogenous variables (see detail in Annex VIII).

In order to correct for the problem of endogeneity, we fit the instrumental variable probit regression model of health symptoms on exogenous variables and endogenous variables that are instrumented. To estimate the relation of air pollution variables to chronic bronchitis and asthma among the adults and ARI among the children, we use the instrumental variable probit regression[10] as shown in equation (4).

$$\Pr(H_{ij}=1)=\alpha+\beta_1\hat{\mathrm{W}}_{\mathrm{j}}+\beta_2 A_{ij}+\beta_3 G_j+e_{ij} \tag{4}$$

[10] As the stove and fuel variables used as explanatory variables are endogenous, we use the ivprob to estimate the probit model. We use the divprob in order to find the marginal effects for ivprob. These two programs implement Amemiya Generalized Least Squares (AGLS) estimators for probit with endogenous regressors (Newey, 1987; equation 5.6). The author of the program is Joe Harkness, Johns Hopkins University, USA, joe.harkness@jhu.edu.

Where, all the symbols are as in equation (3), except t_j, which is the predicted value that comes from the first stage regression of W_j on a set of instruments.[11] We used instruments (a) distance to the market, (b) sex ratio in the family, (c) access to credit, (d) price of LPG, (e) year of use of biogas, (f) maize production squared, (g) ratio of income from non-agricultural sources, (h) ownership of refrigerator, and (i) ownership of television.

Though logically not related, there is a slight spurious correlation of health outcomes with two instruments, the price of LPG and ownership of television. These two instruments are included in the model following the suggestion of Murray (2006) that "strong instruments that are almost valid tend to incur only small biases for two-stage least squares in moderately large samples." The price of LPG and ownership of television are strongly correlated with endogenous variables.

4.4 Household Shadow Value of Health and Benefits of Interventions

We estimate the household shadow values of respiratory diseases using the cost of illness method. The COI estimation includes the direct and indirect core (health-related) and other related (non-health) costs of illness and disability (Kirschstein, 2000). We estimate the core direct costs connected with the use of medicines, diagnostic facilities (X-ray, cough test, etc.) and fees charged by hospitals and doctors. Other related direct costs we include are the fare for transportation to hospitals, to physicians or to other health providers and additional dietary expenses resulting from the illness. The core indirect costs we include are the value of time that patients lose due to morbidity. The other related indirect costs include the value of time lost by caretaking by family members. However, the estimates of the *economic* costs of illness do not capture some aspects of the burden of illness such as reduced functioning, pain and suffering, and deterioration in other dimensions of health-related quality of life including emotional and psychological impacts on families, friends, and co-workers (Kirschstein, 2000). The costs of illness thus estimated due to the health problem are the lower bound of the household shadow value of the respiratory diseases.

To find out the health benefits of the intervention, we multiply the marginal reductions in the diseases due to interventions by the household shadow value of the disease. We compare this benefit from an intervention with the cost of the annual depreciation of the intervention.

5. Results and Discussions

In this section, we identify first the interventions that can reduce indoor air pollution econometrically. Second, we explore the effects of such pollution reducing interventions on chronic bronchitis. We identify thirdly the effects of the interventions on asthma. Fourthly, we explore the effects of the intervention on acute respiratory infections (ARI) among children. Finally, we estimate the health benefits of the pollution reducing interventions.

5.1 Particulate Pollution and Explanatory Variables

As a large proportion of rural households do not perceive IAP as a problem, identification of pollution variables that they too can notice is necessary. The fact that 39 percent of the respondents reported that there is no pollution inside their kitchen shows the extent to which the IAP problem

[11] We treat endogenous regressors as linear functions of the instruments and the other exogenous variables (Maddala, 1983).

has to do with perception – amongst this 39 percent of households, we measured an average pollution level of 2,812 ìg/m^3 of air, which is high by any standard. Those who reported pollution mostly blamed fuelwood as the cause of pollution. This is because the use of other polluting fuels (like animal dung and coal) is very limited. Likewise, electricity is not yet established as a cooking fuel in Nepal. The distribution of the households using different types of cooking fuels in 600 sample households is presented in Table 1. Only two fuels, namely biogas and fuelwood, are being used by more than 20 percent of the sample households (see Fig 1). Thus, we base the analysis mainly on these two major fuels.

We measure PM_{10} in the kitchen of the sub-sample of 99 households both during cooking hours and non-cooking hours. We establish the average PM_{10} level by taking a weighted average of cooking hour readings and non-cooking hour readings, taking the hours of cooking as the weight.[12] The level of average PM_{10} in the kitchen ranges from 2393 to 4209 µg/m^3 with a mean of 3233 µg/m^3 (see Table 2). This result is comparable to earlier studies. Nepal Health Research Council reports that the PM_{10} concentration for cooking areas, where wood is burned, is as high as 8,207 µg/m^3, which is almost twice and four times as high as the concentration for kitchens using kerosene (3414 µg/m3) and LPG (1504 µg/m3), respectively (Winrock International, 2004). Many other studies report that indoor concentrations of particles usually exceed guideline levels by a large margin: the 24-hour mean PM_{10} levels are typically in the range 300–3000 µg/m^3 and may reach 30000 µg/m^3 or more during periods of cooking (Anderson, 1978; Collings, *et al.,* 1990; Martin, 1991; Ellegard 1996; McCracken and Smith, 1998; Albalak *et al.,* 1999). The level of the pollution observed in a Nepalese kitchen is considered alarmingly high in comparison with World Health Organization standards of 50 µg/m^3 and the United States Environmental Protection Agency standards for a 24-hour average PM_{10} concentration of 150 µg/m^3 (EPA, 1997). Galassi *et al.* (2000) find substantial health benefits from a PM_{10} reduction in eight Italian cities whose annual concentrations are far lower (45-55 µg/m^3). For Nepalese households with very high levels of pollution, the health benefits of the reduction therefore are certain to be very high.

To estimate the determinants of pollution, the logarithm of the weighted average PM_{10} is used as the dependent variable. Fuelwood and biogas use as the kitchen fuels are the explanatory variables. Other variables hypothesized to affect kitchen PM_{10} levels are improved cooking stoves (ICS), area of the kitchen, ventilation of the kitchen and cooking hours (see Table 2). More than 20 percent of the sample households use these four measures. We use a dummy for the use of improved cooking stove (ICS). The area of the kitchen is considered to be another variable. We elicit information from the respondents on the length and breadth of the kitchen in order to estimate the area of the kitchen. Meals are generally prepared three times a day. The total number of hours required for preparing meals per day is taken as cooking hours.

The description of explanatory variables for estimating indoor air pollution and their expected signs are presented in Annex II. They include fuelwood, biogas, ICS, kitchen area, kitchen ventilation and cooking hours per day. The results of the ordinary least square estimation of the relationship between IAP level with the set of explanatory variables including fuel and stove show that the level of indoor air pollution is significantly reduced by biogas (9 percent) and ICS (5 percent) (see Table 3). Other variables like fuelwood and ventilation are not found to affect the level of pollution. This is because most of the 99 sample households monitored are found to use

[12] We measure the PM_{10} for a day while the quantity of fuelwood consumption is taken for a year.

fuelwood and have ventilation in the kitchen (fuelwood 96.5 percent, ventilation 94.5 percent). To the same tune also the kitchen area and cooking hours do not affect the level of pollution. The regression equation, though significant, explains only seven percent of the variations in the level of indoor particulate pollution. Thus, this exercise of pollution production function should not be considered a definitive estimation and modeling of exposure to indoor air pollutants. Moreover, this reading of PM_{10} is for just one day of the year—to be more precise, for just two points of time in a 24-hour day. Such a reading of pollution should not be interpreted as the perfect measurement of the factor affecting respiratory diseases.

5.1.1 Diagnosis of Omitted Variables, Heteroskedasticity and Muticollinearity

We checked the regression equation thus estimated for omitted variables, heteroskedasticity and muticollinearity. The test results show that the model has no omitted variable. Similarly, the included variables are homoskedatic (with the exception of fuelwood) and there is no evidence of multicollinearity.

We conducted the Ramsey RESET test, using the powers of the fitted values of the natural log of the daily average PM_{10}. The statistic $F(3, 89)$ is found to be very low (0.68). The test is not significant (probability > F = 0.568). From this result, we infered that the functional form of the model estimated is correct and has no omitted variables bias.

We conducted two separate tests for heteroskedasticity: first, the Breusch-Pagan / Cook-Weisberg test, commonly known as the BP test, which detects heteroskedasticity. Here, the chi-square statistic is very small $\{\chi^2(1) = 0.1\}$ and statistically not significant (probability > χ^2 = 0.750). We can therefore safely infer that the variance of the fitted values of the variable natural log of average particulate matter of size 10 or less is constant. Similarly, we tested the heteroskedasticity of individual variables fitted in the model using the Szroeter's test (see Annex III for the detailed results). The results show that the null hypothesis of homoskedasticity (constant variance) cannot be rejected for the variables except for fuelwood. The fuelwood is slightly heteroskedastic ($p = 0.029$) but it is tolerated for practical purposes.

To test the presence and severity of the multicollinearity, we estimated the variance inflation factor (VIF) and pair-wise correlation among explanatory variables. The mean VIF for the explanatory variables is 1.06 and the highest value of VIF is 1.31, that of biogas. Considering the small value of VIF, we infer that multicollinearity is not a problem in the equation estimated. To confirm the absence of multicollinearity, another test of pair-wise correlation among the explanatory variables was conducted (see Annex IV). The pair-wise correlations among the variables are not more than 0.1 and hence we do not expect the multicollinearity problem. However, the pair-wise correlation between fuelwood and biogas, ICS and kitchen area, biogas and ventilation, fuelwood and cooking hours and cooking hours and kitchen area is significant. Considering the low level of correlation, we decided to tolerate this minor problem for empirical reasons.

Thus, we can conclude that the equation estimated for particulate pollution is statistically significant and valid. The variables that affect the level of indoor air pollution in the given situation are biogas and ICS. These two variables are taken as pollution variables for further analysis of respiratory health effects.

5.2 Health Symptoms and their Determinants

In order to understand the health effects of IAP, we constructed dependent variables from the reported symptoms of respiratory illnesses. We identified explanatory variables, both endogenous and exogenous, logically and screen the instrumental variables.

Table 4 summarizes the symptoms of the respiratory illnesses included in the survey. We take the symptoms of chronic cough (that is, cough on most days for at least 3 months each year) and hemoptysis (bringing up phlegm for 3 months each year) as the symptoms of chronic bronchitis. Similarly, shortness of breath (dyspnea) as characterized by a need to stop for breath when walking at own pace and waking up at night due to attack of shortness of breath we take as the symptoms of asthma.

Cases of acute respiratory infection (ARI) are common among the children. Symptoms of ARI we surveyed included a weakened appetite on the part of the child, abnormal drowsiness and difficulty in waking up, fever or low body temperature, localized chest pain and cough, which is at first dry and painful and later productive and tenacious with rusty sputum or occasionally frank blood-stained. We surveyed the symptoms on a one year recall basis. We developed the disease variables on the basis of the appearance of the symptoms on the individuals. The proportions of individuals suffering from these respiratory diseases are presented in Fig 2.

5.2.1 Exogenous and Endogenous Explanatory Variables

The explanatory variables of respiratory diseases include cooking technology (improved cook stove) and fuel use (biogas, LPG and wood). ICS and biogas are dummies while the other two are continuous variables. The cooking technology and fuel variables are endogenous as the decision of the households for stove choice and fuel choice can be affected, in turn, by the health problems they are facing. Most of the IAP studies assume that the levels of the behaviour-related variables are determined by factors other than those under study that is that they are exogenous. In fact there is widespread evidence that people are not passive acceptors of risks to their health, but that they adjust their behaviour because of their perceptions of their health and the risks to their health (Briscoe *et al.* 1990). Households facing more problems of respiratory health may decide to adopt ICS or biogas depending on their preference.

The exogenous variables are the personal characteristics that may affect health status like age and gender. Similarly, geographical characteristics like hill and plain can affect respiratory health and are also exogenous. We present the description of these endogenous and exogenous explanatory variables and their expected signs in Table 5.

The problem of endogenous variables creates a system of simultaneous equations. Researchers generally use the reduced form equation of two stages least square to solve the problem. To this effect, we identified and employed instrumental variables.

5.2.2 Choosing the Right Instruments

Studies show that people are not passive acceptors of risks to their health. They modify their behavior in accordance with their perceptions of their health status and the perceived risks to health (Briscoe, *et al.*, 1990). Several household decisions relating to the emissions of smoke pollution and the exposure of family members to pollution may potentially be endogenous. Literature suggests an instrumental variable (IV) method, mostly employed in epidemiological studies, to address the problem (Greenland, 2000; and Hernan and Robins, 2006). We attempted to identify potential instruments for this purpose.

We take distance to the nearest market as one of the instrumental variables. Household isolation variables include the distance to the nearest hospital or health post, distance to the nearest medical store, distance to nearest market place and distance to the road head. We measure distance in terms of the number of minutes it takes to reach through the most commonly used mode of transport. Annex V provides descriptive statistics of such variables. The biggest distance is for the hospital/health post and the closest is for the road head. But these four distances to utility variables are highly and positively correlated pair-wise (see Annex VI for detail). The correlation ranges from the 0.2 between the distance to the nearest hospital/health post and market to as high as 0.8 between medical store and market. This is because the medical stores are generally located in the market area. Among these four distance variables, the distances to the market and the medicals have the minimum standard deviations. Logically the distance to the market and the medicals cannot have a health effect. Hence the distance to the market and the medical are the candidates for the instrumental variables. The distance of the household from the market is not significantly correlated with study variables of chronic bronchitis, asthma and ARI. Therefore, this is a valid instrument (please see Annex VII for detail). But the distance to the medical store is somehow significantly correlated with one of the study variable, asthma, and is an invalid instrument. The distance to the market is significantly correlated with the endogenous variables (ICS, biogas, LPG and fuel wood). However, the degree of correlation ranges from 0.05 to 0.31 (see Annex VIII for detail). Hence, the distance to market is a valid instrument with an acceptable strength.[13]

Another probable instrument is sex ratio in the family. Since the sex ratio in the family is out of the control of the household and has no association with the study variable, at least in the short run, it is a valid instrument. As it is moderately correlated with some of the endogenous variables, it has some strength. Using the same standards and also considering the correlation of the variables with other valid instruments, we have used access to credit, price of LPG, year of use of biogas, maize production squared, non-agricultural income as a percent of the total income, and refrigerator and television as instrumental variables in the study.

The descriptive statistics of the endogenous variables, exogenous variables, instrumental variables and study variables (chronic bronchitis and asthma) are presented in Table 6 for 2,739 individuals of 600 households. Table 7 presents the descriptive statistics of the endogenous, exogenous, instrumental and study variables (acute respiratory infections) separately for 301 children of age five or less in 600 sample households.

We measure distance to the nearest market in terms of the time it takes to reach using the most commonly available mode of transport. On an average, the households take 41 minutes to reach the nearest markets. Since not all households have male members, the sex ratio (female to male ratio) is missing for those households without male members. Access to credit is a dummy at

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13 An instrument with a significant and higher (0.30 or more) correlation coefficient with at least one endogenous variable is taken as a strong instrument whereas that with significant but weaker (less than 0.30) correlation coefficient is taken as an acceptable instrument.

household level; 69 percent of the households report that they have easy access to credit at times of need. The price of LPG includes the cost incurred by households to buy and transport it home. The price of LPG ranges from Rs 63 to Rs 70 per kg (about one US dollar). The year of biogas use is as high as 17 years with the average at two years. This means that biogas intervention is a recent phenomenon.

Similarly, maize production per household is in quintal per year. To make it valid for the use as an instrument square of the maize production is taken. Another IV is the ratio of non-farm income to the total income. Nearly 51 percent of the income is from the non-agriculture sector and the rest from the agriculture sector. Around six percent of the households have a refrigerator while 48 percent can lay claim to a television. The descriptive statistics are presented separately for a sub-sample of the households that have children of five years or less. Such variables are used for the analysis of ARI among children.

The effects of stove choice and fuel choice on major respiratory health problems like chronic bronchitis, asthma and acute respiratory infections (ARI) are discussed in this section. We obtain these results with and without making corrections for endogeneity.

5.2.3 Effects of Stove and Fuel Choice on Chronic Bronchitis

We assess the effects of indoor air pollution related variables on the appearance of the symptoms of chronic bronchitis on individual members of the households using simple probit (see results in Annex IX) as well as instrumental variable probit (see Table 8). Fig 3 presents a comparison of results. The results from the simple probit that suffer from the problem of endogeneity differ from the results obtained through the instrumental variable probit that corrects for the problem of endogeneity.

The simple probit regression shows illogical results that chronic bronchitis significantly decreases with increases in the quantity of fuel wood consumption whereas ICS and biogas do not significantly reduce the symptoms associated with the illnesses (Annex IX). After correcting for the problem of endogeneity, the IV probit gives logically sound results (Table 8) that ICS and biogas significantly reduce the symptoms of chronic bronchitis; fuelwood on the other hand does not. For the endogenous variables, namely, ICS, biogas, LPG and fuelwood, both the coefficients and slopes increase after corrections for endogeneity. The sign and magnitude of the coefficients and slope of the exogenous variables remain the same with the exception of the hill variable. In the case of the hill variable, the size of the coefficient increases after correcting for endogeneity. The log likelihood ratio, chi-square value and the pseudo coefficient of multiple determinations remain the same in both cases. The equation explains about 21 percent of the variations in chronic bronchitis. The overall equation is statistically significant.

The results, after correcting for endogeneity (Table 8), show that the use of ICS and biogas significantly reduces the symptoms of chronic bronchitis among the residents. ICS reduces chronic bronchitis by over nine percent while biogas does so by over one percent. The problem of chronic bronchitis is more severe in old age. It is also worse among women. This is because women are more exposed than men to the cooking stove. The problem of chronic bronchitis is also more severe in the hill region than in the plain.

5.2.4. Effects of Stove and Fuel Choice on Asthma

The results obtained from the simple probit (see Annex X for results) and instrumental variable probit (see Table 9) are similar in direction but different in magnitude in the case of asthma (see Fig 4). Both results show that biogas significantly reduces the problem of asthma and that ICS has no significant effect. It is surprising to note that the use of fuelwood decreases the problem of asthma. Pistelly (1997) reports similar findings about wood smoke and asthma. Bruce *et al.*, (2000) also conclude that asthma is less common among rural populations where biomass fuel use is more common.

The effects of biogas on asthma are to be expected as biogas reduces smoke emissions as presented in Table 3 above. But the result for fuelwood is unexpected. We could hypothesize that asthma is mainly the result of past exposures. Furthermore, the use of fuelwood in the dwelling house has the effect of space heating which is also considered therapeutic in the case of asthma patients.

The results also show that the problem of asthma increases with the increase in age. It is more severe among women as compared to men. Thus, the use of biogas as a cooking fuel reduces the problem of asthma illness among the rural poor. The equation explains about 16 percent variation in asthma among rural women and men.

5.2.5 Effects of Stove and Fuel Choice on Acute Respiratory Infections

We assessed the effects of stove and fuel choice on acute respiratory infections among children of five years and less using simple probit (see Annex XI for results) and instrumental variable probit (see Table 10). The results obtained after the adjustment for endogeneity is different from the results without the adjustment (see Fig 5). The use of biogas reduces the problem of ARI under both the estimates but the size of coefficients and slope increases after the adjustment. The use of biogas as cooking fuel reduces the problem of ARI nearly by half (43 percent).

The problem of ARI decreases with the increase in age. The problem is not significantly different for girls and boys, and on the hills and in the plains. The use of ICS does not affect the problem of ARI among the children. The coefficient of multiple determinations (pseudo R^2) decreases after making the adjustment for endogeneity. The equation after adjustment explains only four percent of the variations in ARI. The only policy variable available to reduce the problem of ARI is the adoption of biogas.

5.3 Health Benefits

We estimate the health benefits of indoor air pollution reducing interventions using the household shadow value of respiratory diseases and the marginal reduction in health problems due to interventions.

5.3.1 Household Shadow Value of Health

We estimate the household shadow values of health for chronic bronchitis, asthma and ARI directly from the cost of illnesses survey of the households (see Table 11). The estimated household shadow value of chronic bronchitis is Rs 2,576. This includes the treatment costs and opportunity costs of the time lost[14] due to diseases. The household shadow value of asthma is Rs 2,121 and that of ARI Rs 4,298 (see Fig 6). Over 80 percent of these costs are for medicines. Around four percent is for doctors' and hospital fees. The costs of diagnostic tests are still lower (see Figs 7, 8 and 9). The opportunity costs of the time lost due to travel to and stay in hospitals or to health posts and inability to work as well as the time lost by caretakers (see Annex XII for detail) range from about four percent in ARI to 10 percent in asthma. As the labour market in the study area is far from complete, the opportunity cost of time lost is taken as 45 percent of the wage rate (Adhikari, 1988). If we can reduce the probability of these diseases through interventions for IAP reduction, the costs of illnesses too could be reduced presumably in the same proportion.

5.3.2 Benefits of Improved Stove and Biogas

We estimate the annual reduction in the health costs per intervention of stove and biogas based on the marginal reduction in health problems such as chronic bronchitis, asthma and ARI through these interventions and household shadow value of health. We find that ICS plus heaters reduce the risk of chronic bronchitis by 0.092, thereby reducing health costs by Rs 237 per person per annum (see Table 12). Taking into account family size as weight per household, the average reduction in health costs by the intervention is Rs 1,217 per annum (see Table 13).

On the cost side, the average market price[15] of ICS and heater is Rs 605 (see Table 13). Taking the average life of ICS plus heaters, as 10 years, and taking the linear depreciation of the ICS and heater into account, the annual depreciation can be calculated at Rs 60. This shows that the annual health benefits from each ICS or heater on average is 20 times higher than the annual cost of this intervention. This analysis, however, takes into account only the health benefits and not the energy efficiency benefits of the intervention. The energy efficiency benefits are direct and more visible to the households and funders than the health benefits when it comes to decision making. The external benefit of the ICS not taken into account in this comparison is the reduction in green house gas emissions from reducing fuelwood consumption. Improved cookstoves promoted in Nepal are estimated to be 35 per cent more efficient than traditional stoves (Bluffstone, 1989; Sulpya, 1989). The stove reduces fuelwood consumption and hence the emission of carbon to the atmosphere.

Similarly, we found a biogas plant to reduce the risk of chronic bronchitis by 0.014, asthma by 0.011 and ARI by 0.159, thereby reducing the annual health cost by Rs 59 per adult and Rs 683 per child. Taking into account the family size and demographic features of the rural household as weight, the weighted annual reduction in the health costs due to the intervention of a biogas plant is Rs 647 per household. A typical biogas plant costs Rs 19,615 to the household. Taking 30

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[14] We exclude the costs of pain and sufferings due to problems in estimation. The cost estimate is the cost of morbidity. Estimating the costs of mortality is out of the scope of this study.

[15] The shadow price of ICS plus heater would however be slightly higher than this amount due to certain intervention programs for ICS. Since the analysis is done with household perspective, we use the market price for the purpose.

years as the reasonable life-time of a biogas plant as well as the fact of linear depreciation, the annual depreciation comes to Rs 654 (see Fig 10). Thus the annual health benefit from a biogas plant is nearly equal (99 percent) to the annual average costs of a biogas plant. The energy efficiency benefit of the intervention is in addition to this health benefit. Adoption of a biogas plant shifts cooking fuel from solid to gas and has implications to green house gas emission as well. Reduced solid fuel consumption reduces carbon emission and controlled production of cooking gas reduces methane escape to the atmosphere. Such benefits are not taken into account and the study confines itself to the health benefit analysis.

The comparison of health benefits and costs shows that there is no reason for not buying the intervention. In addition there is energy benefit that is more visible to the households. Under the assumption of full information, even they ignore the external benefits of environmental protection and climate change, the households would have adopted ICS and biogas and maximized their benefits. Thus the assumption of full information is not applicable in this case when some costs and benefits are hidden. Even scientists find it difficult to desegregate the effects and estimate the health benefits precisely due to endogeneity bias and other confounding factors like outdoor air pollution. As the study is conducted in rural area, the outdoor air pollution is not a problem in the study area.

Households invest in pollution-reducing interventions on the basis of the costs and benefits they perceive and internalize. The market price of the intervention is known; what is unknown is most probably the health benefits that are indirect. There is a need to make the rural households aware of the health benefits of the intervention so that a larger proportion of the rural households will adopt the interventions and reduce thereby their health costs at the same time protecting the environment and climate.

6. Conclusions and Recommendations

The analysis starts with a screening of pollution variables. Pollution variables like stoves and fuels are more visible to the households than the actual measure of emission concentrations. Many of the rural people, who have been using solid fuels for generations, do not generally regard indoor smoke as a problem *per se*. But the actual measurement of the level of pollution shows that the level of particulate matter pollution inside the average kitchen is alarmingly high. The level of average PM_{10} in the kitchen ranges from 2393 to 4209 $\mu g/m^3$ with a mean of 3233 $\mu g/m^3$. This level of pollution is quite high compared to World Health Organization standards (50 $\mu g/m^3$) and the United States Environmental Protection Agency standards (150 $\mu g/m^3$) (EPA, 1997). Most households use fuelwood for cooking, however, the use of coal is not very popular.

The pollutants production function analysis shows that the level of indoor air pollution (IAP) is affected in a significantly negative manner by improved cook stove (ICS) and biogas. Biogas fuel reduces the indoor air pollution by nine percent and ICS reduces it by five percent. As most of the 99 sub-sample households use fuelwood (96.5 percent) and have ventilation in the kitchen (94.5 percent) we find slight variations in PM_{10} when it comes to these variables. We conclude from the analysis that of the cooking fuels available in the rural areas, ICS and biogas will lead to significant reductions in IAP.

We assess the effects of IAP reducing interventions on the appearance of the symptoms of chronic bronchitis, asthma and ARI on individual members of the households using two approaches:

one that assumes behaviors are exogenous (e.g., using a probit model) and the other which assumes that behavior is endogenous (using an instrumental variable probit model). The results from the two types of analysis are found to be different for all the three diseases under consideration. The results obtained after correcting for endogeneity using the instrumental variable probit gives more reliable results, that is, in addition to age and gender, the use of improved stove and biogas significantly reduces respiratory health problems. Thus, historical estimates of the effects of indoor air pollution on health may have to be revised by correcting for the endogeneity problem.

Our analysis suggests that the problem of respiratory health is more severe among older age cohorts, particularly among those who are female. As cooking is generally done by women, they suffer more from respiratory problems. Hence, they require special attention from health workers and development partners who are interested in reducing the health effects of indoor air pollution.

Promotion of the improved stoves and biogas in rural areas can help save the rural people from respiratory health problems arising from indoor air pollution. An improved stove can reduce health costs by Rs 1,217 per year. This benefit is 20 times higher than the annual depreciated cost of an improved stove. Similarly, a biogas plant, with an annual depreciated cost of Rs 654, is found to reduce annual health cost by Rs 647. This would lead us to the conclusion that the cost of a biogas plant is almost equal to its health benefits. In addition, ICS and biogas have the added benefits of energy efficiency to the households and environmental benefits to the society. The estimates of health benefits in this study, however, do not include such costs or the costs of the pain and suffering to sick people and the costs of mortality. This means the estimates are the lower bound of the benefits of intervention.

In spite of the much higher benefits of ICS and biogas as compared to their costs, why is it that a large proportion of the rural people are still to adopt these interventions. Perhaps an 'information gap' is the reason. Households invest in pollution reducing interventions on the basis of the costs and benefits they perceive. The health benefits of improved stove and biogas are indirect and not adequately perceived by the rural people who are mostly less educated or illiterate. There is a need to make the rural households aware of the health benefits of interventions so that a larger proportion can adopt the intervention and thereby save significantly on health costs. We however, recommend further studies to compare the complete costs and benefits of different interventions that are known to reduce indoor air pollution.

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TABLES

Table 1: Descriptive Statistics of Fuel Use for Cooking by Sample Households

	Fuel	Unit	n	Mean	Standard deviation	Percent household using the fuel
1	Fuelwood	Dummy	600	0.965	0.184	96.5
2	Biogas	Dummy	600	0.283	0.451	28.3
3	LPG	Dummy	600	0.192	0.394	19.2
4	Electricity	Dummy	600	0.087	0.282	8.7
5	Coal	Dummy	600	0.045	0.207	4.5
6	Kerosene	Dummy	600	0.023	0.151	2.3
7	Dung cake	Dummy	600	0.018	0.134	1.8

Source: Household Survey 2005

Table 2: Descriptive Statistics of Stove, Kitchen and Cooking Hours

	Variable	Unit	n	Mean	Standard deviation	Minimum	Maximum
1	ICS	Dummy	600	0.252	0.434	0	1
2	Kitchen area	Square feet	600	50.435	29.809	6.000	222.750
3	Ventilation	Dummy	600	0.945	0.228	0	1
4	Cooking hours	Hours/day	600	2.339	0.757	0.500	6.000
5	Average daily PM10	μg/m3	99	3233.05	435.75	2393.71	4209.44
6	Log of average daily PM10	μg/m3, taken natural log	99	8.07	0.13	7.78	8.35

Source: Household Survey 2005

Table 3: Factors Affecting the Daily Average PM_{10} inside the Kitche

		Coefficient	Standard error	95% Confidence Interval	
1	Fuelwood	-0.065	0.059	-0.183	0.053
2	Biogas	-0.053*	0.029	-0.111	0.005
3	ICS	-0.089***	0.030	-0.149	-0.029
4	Kitchen area	0.001	0.000	0.000	0.002
5	Ventilation	0.007	0.056	-0.104	0.118
6	Cooking hours	-0.002	0.015	-0.033	0.029
7	Constant	8.152***	0.094	7.966	8.339
	Number of observations = 99 Adjusted R^2 = 0.072			F(6, 92) = 2.260 Probability > F = 0.044	

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Table 4: Symptoms and Conditions of Chronic Bronchitis, Asthma and ARI

	Symptoms*	Condition	Probable Case
A	Cough for most days for 3 months each year	Chronic Cough	Chronic Bronchitis
B	Bring up phlegm for 3 months each year	Hemoptysis	
C	Stop for breath when walking at own pace	Shortness of Breath (dyspnea)	Asthma
D	Woken at night by attack of shortness of breath	Shortness of Breath (dyspnea)	
E	Child stopped feeding well		Acute Respiratory Infections (ARI)
F	Child abnormally sleepy or difficult to awake		
G	Fever or low body temperature		
H	Localized chest pain		
I	Cough at first dry and painful, later productive and tenacious with rusty sputum or occasionally frank blood stained		

* Or medically identified case of bronchitis (a+b), asthma (c+d), or acute respiratory symptoms (e to i).

Table 5: Factors Affecting Chronic Bronchitis, Asthma and ARI with Their Expected Signs

	Variable	Description	Expected Sign
1	ICS plus heaters	Household using improved cooking stove for firewood and electricity, yes/no	-
2	Biogas	Having a functioning biogas plant, yes/no	-
3	LPG	Use of LPG in kg per year	-
4	Wood	Use of Fuelwood in quintal per year	+
5	Age	Age of the individual in years	+ (bronchitis & asthma), - (ARI)
6	Gender	Female (1) and male (0)	+ (bronchitis & asthma), - (ARI)
7	Hill	Hill (1) geographical area and plain (0) area	+

Table 6: Descriptive Statistics of Study Variables, Endogenous, Exogenous and Instrumental Variables for Adults

	Variable	Unit	n	Mean	Standard deviation	Minimum	Maximum
	Endogenous Variables						
1	ICS plus heaters	incidence	2739	0.44	0.50	0	1
2	Biogas	incidence	2739	0.31	0.46	0	1
3	LPG	kg/year	2739	12.11	28.70	0	170.4
4	Wood	qt/year	2739	12.64	6.45	0	62.4
	Exogenous Variables						
5	Age	year	2739	33.42	17.38	11	95
6	Female	yes/no	2739	0.50	0.50	0	1
	Instrumental Variables						
7	Hill	yes/no	2739	0.50	0.50	0	1
8	Distance to the market	minutes	2739	41.38	21.01	1	60
9	Sex ratio in the household	ratio	2723	1.18	0.87	0	9
10	Access to credit	yes/no	2739	0.69	0.46	0	1
11	Price of LPG	Rs/kg	2739	66.37	1.54	63.38	70.42
12	Year of use of biogas	year	2739	2.03	3.70	0	17
13	Maize production squared	qt	2739	45.21	217.61	0	3600
14	Ratio of income from non-agricultural sources	%	2736	50.72	31.51	0	100
15	Refrigerator	incidence	2739	0.06	0.23	0	1
16	Television	incidence	2739	0.48	0.50	0	1
	Study Variables						
17	Chronic bronchitis	incidence	2739	0.055	0.228	0	1
18	Asthma	incidence	2739	0.034	0.181	0	1

Table 7: Descriptive Statistics of Study Variables, Endogenous, Exogenous and Instrumental Variables for Children (<=5 years)

	Variable	Unit	n	Mean	Standard deviation	Minimum	Maximum
	Endogenous Variables						
1	ICS plus heaters	incidence	301	0.35	0.48	0	1
2	Biogas	incidence	301	0.25	0.43	0	1
3	LPG	kg/year	301	13.29	33.88	0	170.4
4	Wood	qt/year	301	12.66	6.89	0	43.2
	Exogenous Variables						
5	Age	year	301	3.20	1.40	1	5
6	Female	yes/no	301	0.52	0.50	0	1
7	**Hill**	yes/no	301	0.47	0.50	0	1
	Instrumental Variables						
8	Distance to the market	minutes	301	40.79	21.94	1	60
9	Sex ratio in the family	ratio	299	1.32	1.09	0.2	9
10	Access to credit	yes/no	301	0.64	0.48	0	1
11	Price of LPG	Rs/kg	301	66.18	1.67	63.38	70.42
12	Year of use of biogas	year	301	1.37	3.21	0	16
13	Maize production squared	qt	301	25.75	82.14	0	900
14	Ratio of income from non-agricultural sources	%	301	52.5.5	31.93	0	100
15	Refrigerator	incidence	301	0.06	0.23	0	1
16	Television	incidence	301	0.49	0.50	0	1
	Study Variable						
17	ARI	incidence	301	0.671	0.471	0	1

Table 8: Effects of Fuel Use and Stove Adoption to Chronic Bronchitis

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	ICS plus heaters+	-1.507**	-0.092**	0.051	0.436	-0.192	0.008
2	Biogas+	-0.276*	-0.014*	0.007	0.313	-0.028	-0.001
3	LPG	0.013	0.001	0.001	12.175	0.000	0.002
4	Wood	-0.050	-0.003	0.003	12.617	-0.008	0.003
5	Age	0.031***	0.002***	0.000	33.360	0.001	0.002
6	Female+	0.535***	0.032***	0.006	0.493	0.019	0.045
7	Hill+	1.042***	0.068***	0.025	0.494	0.018	0.118
8	Constant	-2.562***		Log likelihood	LR chi2(7)	244.53	
9	Observed P		0.055	n = 2739	Prob > chi2	0.000	
10	Predicted P		0.024	(at x-bar)	Pseudo R2	0.214	

(+) dF/dx is for discrete change of dummy variable from 0 to 1

Note: Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Table 9: Effects of Fuel Use and Stove Adoption on Asthma

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	ICS plus heaters+	-0.806	-0.032	0.033	0.436	-0.097	0.032
2	Biogas+	-0.285*	-0.011*	0.006	0.313	-0.021	0.000
3	LPG	0.010	0.000	0.000	12.175	0.000	0.001
4	Wood	-0.140***	-0.006***	0.002	12.617	-0.010	-0.001
5	Age	0.023***	0.001***	0.000	33.360	0.001	0.001
6	Female+	0.704***	0.031***	0.006	0.493	0.020	0.043
7	Hill+	0.569	0.025	0.017	0.494	-0.009	0.058
8	Constant	-1.440**		Log likelihood	LR chi2(7)	127.81	
9	Observed P		0.034	n = 2739	Prob > chi2	0.000	
10	Predicted P		0.016	(at x-bar)	Pseudo R2	0.159	

(+) dF/dx is for discrete change of dummy variable from 0 to 1
Note: Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Table 10: Effects of Fuel Use and Stove Adoption on ARI among the Children (age<=5)

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	ICS plus heaters+	0.189	0.067	0.266	0.351	-0.454	0.588
2	Biogas+	-0.427*	-0.159*	0.090	0.244	-0.335	0.017
3	LPG	-0.004	-0.002	0.003	13.382	-0.007	0.004
4	Wood	0.044	0.016	0.011	12.592	-0.006	0.038
5	Age	-0.120**	-0.043**	0.022	3.191	-0.087	0.001
6	Female+	-0.206	-0.074	0.057	0.515	-0.186	0.039
7	Hill+	-0.162	-0.058	0.141	0.462	-0.335	0.219
8	Constant	0.566		Log likelihood	LR chi2(7)	14.34	
9	Observed P		0.671	n= 301	Prob > chi2	0.046	
10	Predicted P		0.678	(at x-bar)	Pseudo R2	0.038	

(+) dF/dx is for discrete change of dummy variable from 0 to 1,
Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Table 11: Household Shadow Value of Illnesses Estimated by Costs of Illness Method

	Cost headings	Unit	Chronic bronchitis		Asthma		ARI	
			Rs	%	Rs	%	Rs	%
1	Medicine Costs	Rs	2,107.50	81.8	1,706.00	80.4	3,604.20	83.9
2	Laboratory Costs (X-ray, cough test, etc.)	Rs	64.3	2.5	57	2.7	173.4	4.0
3	Hospital/Doctor Fees	Rs	104.1	4.0	92	4.3	224.9	5.2
4	Travel Costs to and from for the treatments	Rs	43.9	1.7	41.9	2.0	88.1	2.0
5	Additional dietary expenses resulting from illness	Rs	19	0.7	18	0.8	31.4	0.7
6	Opportunity cost of time lost	Rs	237.38	9.2	206.46	9.7	176.04	4.1
	Total costs of illness	Rs	2,576.18	100.0	2,121.36	100.0	4,298.04	100.0

Source: Household survey 2005.

Table 12: Health Benefits of Intervention to the Individuals

	Particulars	Unit	IAP reducing intervention	
			ICS plus heaters	Biogas
1	Change in chronic bronchitis	dF/dx	-0.092	-0.014
2	Change in asthma	dF/dx	0	-0.011
3	Change in ARI	dF/dx	0	-0.159
4	Reduction in costs of chronic bronchitis	Rs	-237.01	-36.07
5	Reduction in costs of asthma	Rs	0	-23.34
6	Reduction in the costs of ARI	Rs	0	-683.39

Table 13: Costs of the Interventions and their Annual Health Benefits per Household

	Particulars	Unit	n	Mean	Standard deviation	Minimum	Maximum
	Cost of intervention						
1	Price of ICS plus heater	Rs/unit	370	604.85	504.07	60.00	4,000.00
2	Price of biogas	Rs/unit	170	19,614.71	4,251.01	11,000.00	35,000.00
3	Price of ICS plus heater	Rs/year	370	60.49	50.41	60.00	400.00
4	Price of biogas	Rs/year	170	653.82	141.70	367.00	1,167.00
	Health benefits of intervention						
5	Adult health benefits of ICS plus heater	Rs/hh	600	1,216.65	442.65	237.01	2,370.10
6	Adult health benefit of biogas	Rs/hh	600	304.97	110.96	59.41	594.10
7	**Child health benefits of ICS plus heater**	Rs/hh	600	0.00	0.00	0.00	0.00
8	Child health benefit of biogas	Rs/hh	600	341.70	513.35	0.00	2,733.56
9	Annual health benefits of ICS plus heater	Rs/hh	600	1,216.65	442.65	237.01	2,370.10
10	Annual health benefit of biogas	Rs/hh	600	646.67	521.71	59.41	3,030.61

Note: hh = household

FIGURES

Figure 1: Proportion of household using different fuel

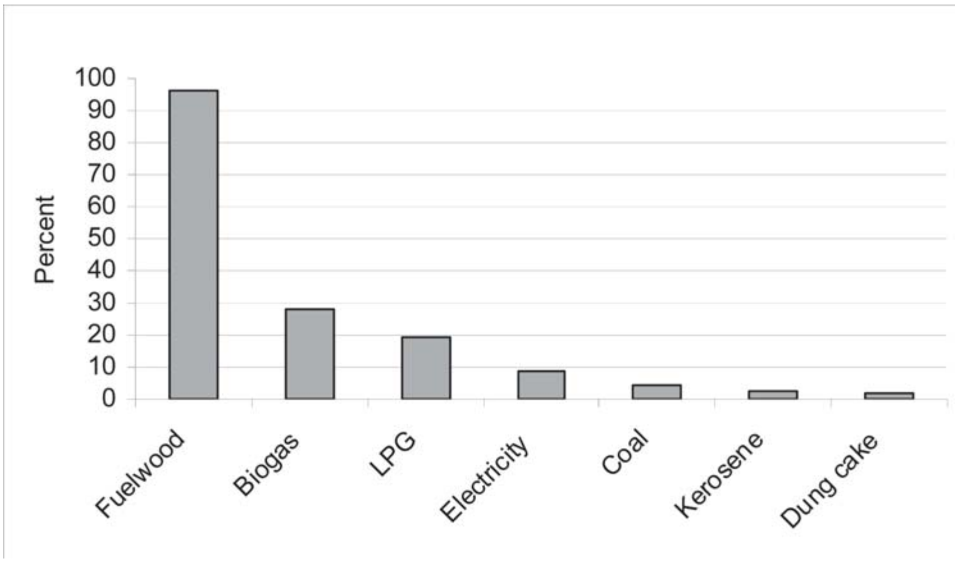


Figure 2: Percent of People suffering from Respiratory Diseases

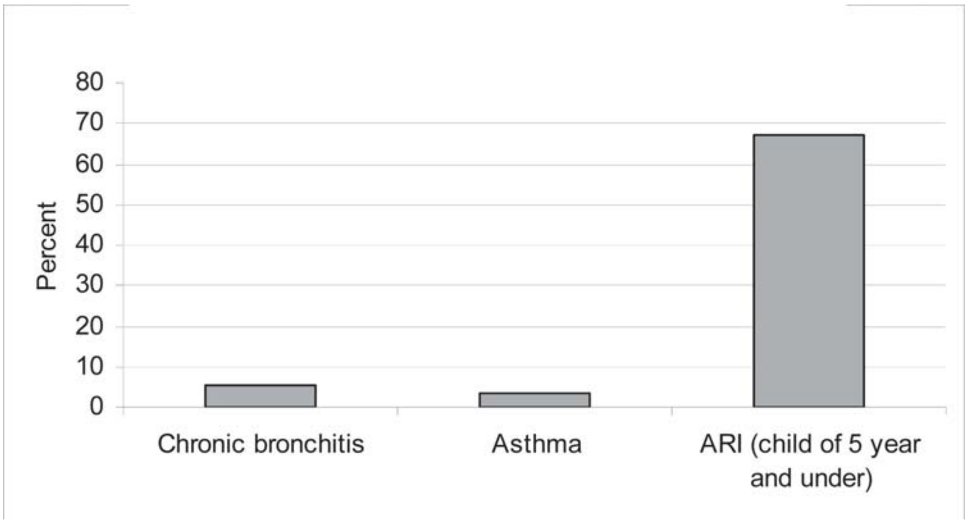


Figure 3: Magnitude of Coefficients for Chronic Bronchitis with and without IV

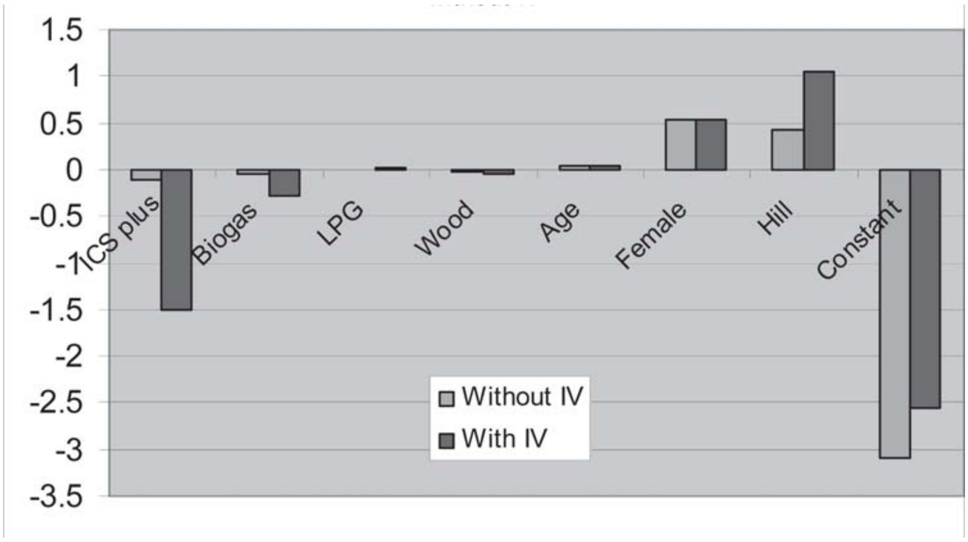


Figure 4: Magnitude of the Coefficients for Asthma with and without IV

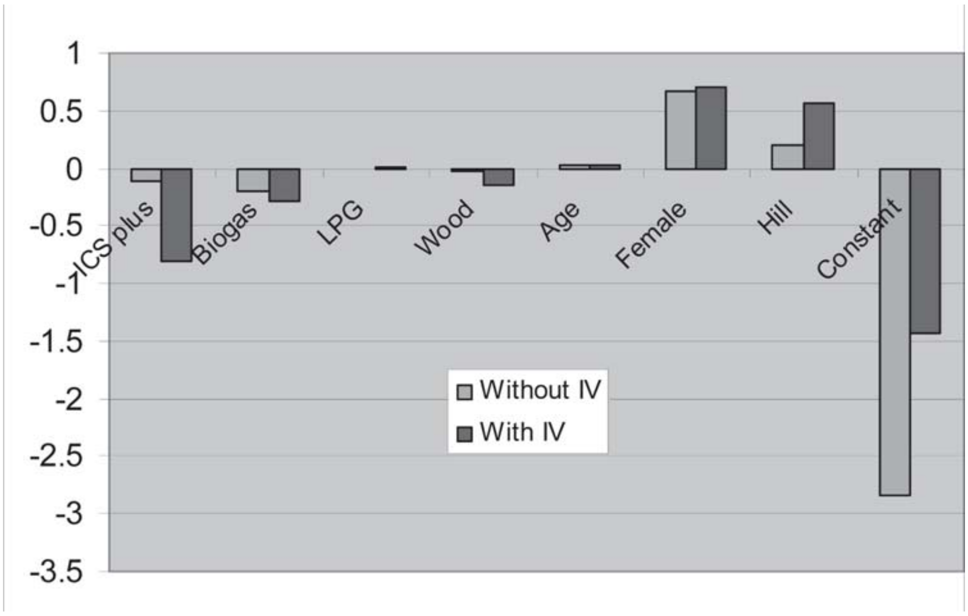


Figure 5: Magnitude of the Coefficients for ARI with and without IV

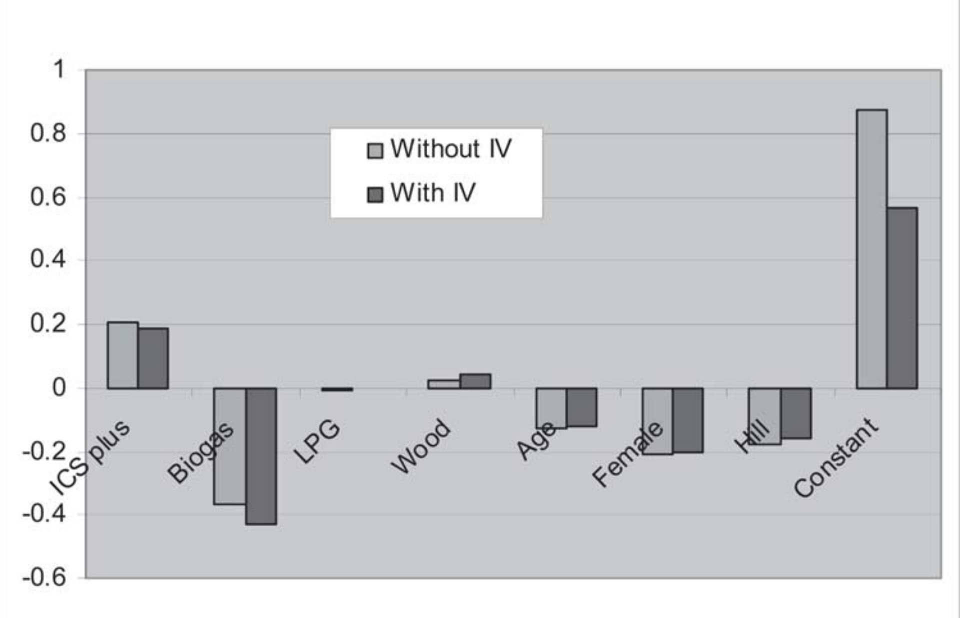


Figure 6: Costs of Respiratory Illnesses

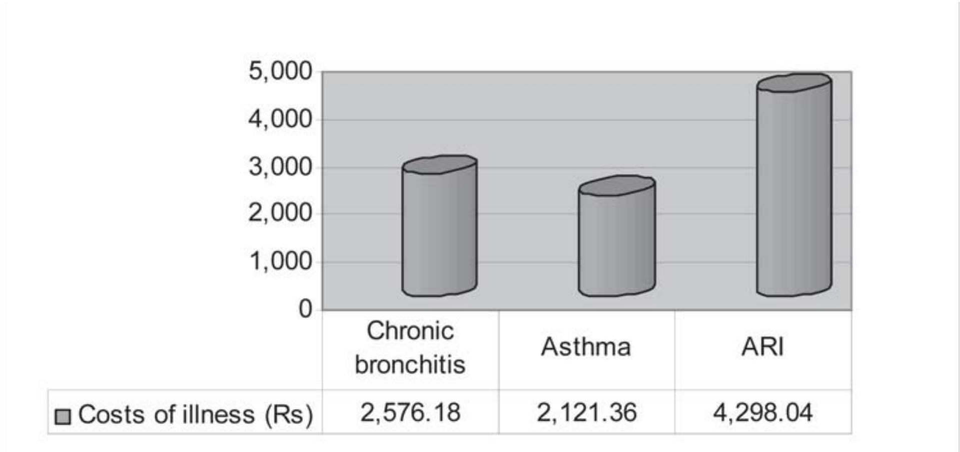


Figure 7: Costs of Chronic Bronchitis

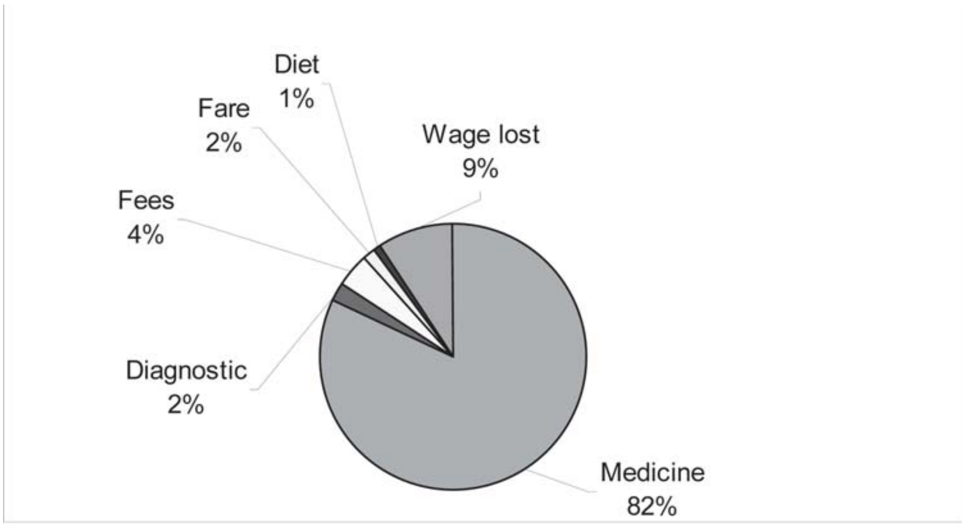


Figure 8: Costs of Asthma

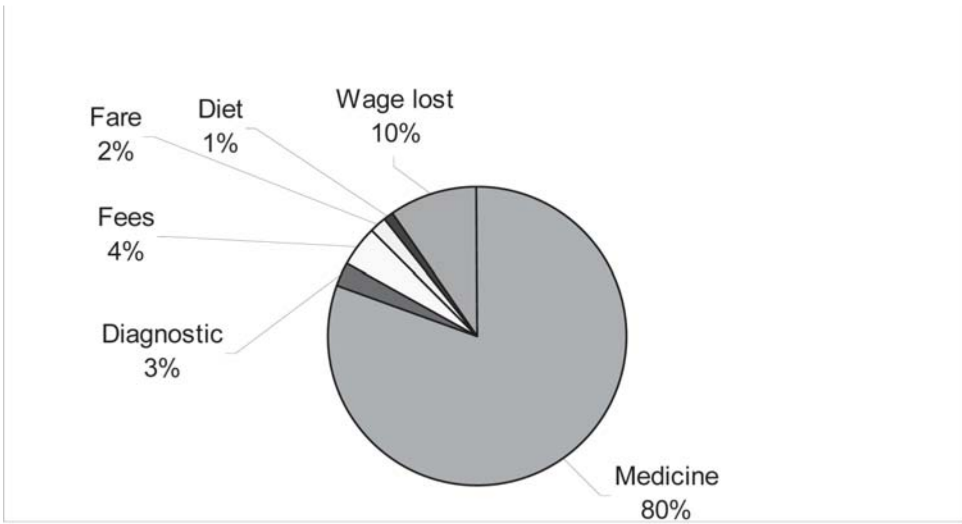


Figure 9: Costs of Acute Respiratory Infections for Children

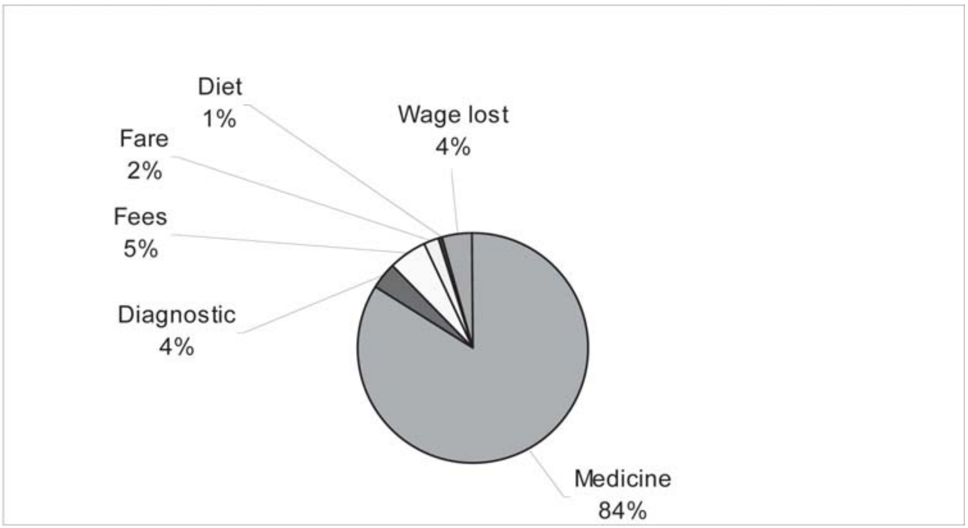
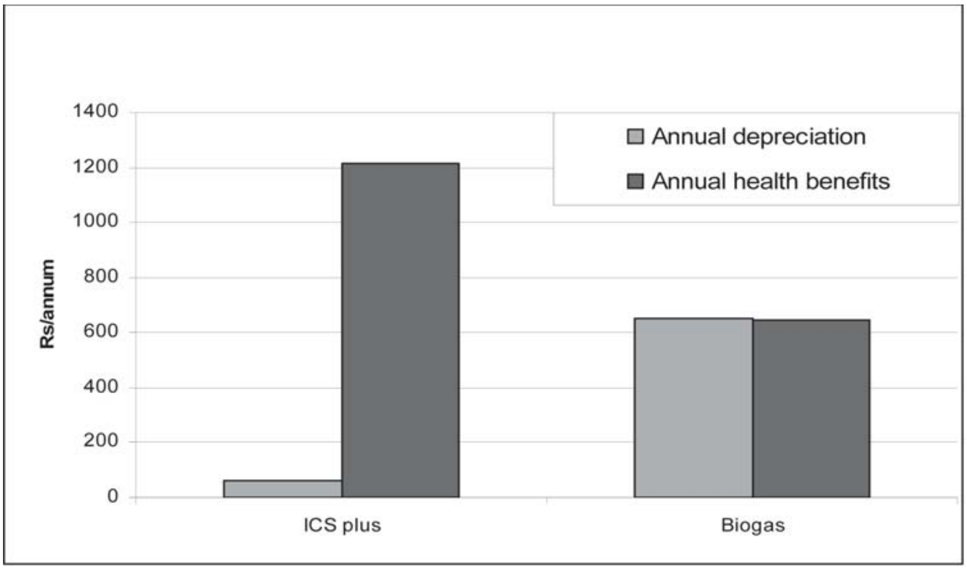


Figure 10: Reduction in Health Costs by Interventions



MAP

Map 1: Study Area and Sample Districts

APPENDIX 1

Annex I: Household Survey Questionnaire

This survey is conducted for the purpose of research on indoor air pollution titled "Demand for Alternative Technologies for Reduction of Indoor Air Pollution in the Rural Areas of Central Nepal" by the Center for Economic Development and Administration (CEDA), Tribhuvan University, with the assistance of South Asian Network for Development and Environmental Economics (SANDEE). The information obtained in this questionnaire will be used only for research purposes. Personal information provided will be kept confidential. The research team kindly requests the sample households to cooperate in the research by providing accurate information. Your help will be duly acknowledged. — CEDA.

Household No:——————
District: ——————
VDC: ——————
Ward No: ——
Village: ——————————

Enumerator ——————————
Date ——————————

1. Name of the household head (from sample) ☐ Male ☐ Female
2. Name of the respondent ☐ Male ☐ Female
3. Do you think there is air pollution due to smoke inside your house? ☐ Yes ☐ No
   If yes, which fuel is responsible for pollution?
   ☐ Fuelwood ☐ Agricultural waste ☐ Animal dung ☐ Coal
   ☐ Kerosene ☐ Biogas ☐ LPG ☐ Electricity
4. Which fuel do you prefer for cooking?
   ☐ Fuelwood ☐ Agricultural waste ☐ Animal dung ☐ Coal
   ☐ Kerosene ☐ Biogas ☐ LPG ☐ Electricity
5. Which of the following fuels in use best reduce indoor air pollution? *(√ all applicable)*
   ☐ Fuelwood ☐ Agricultural wastes ☐ Animal dung ☐ Coal
   ☐ Kerosene ☐ Biogas ☐ LPG ☐ Electricity

6. Which of the fuels do you use most for the purposes outlined below? Put “1” for Yes, and “0” for No

Serial No	Do you use the following fuel?	Unit	Price in Rs	Used for				
				Cooking	Cook feed (kundo)for the animals	Water heating	Home/room heating	Lighting
1	☐ Electricity	Unit			0			
2	☐ Solar power	Construction						
3	☐ LPG	Cylinder						
4	☐ Biogas	Construction						
5	☐ Kerosene	Liter						
6	☐ Coal	kg						0
7	☐ Fuelwood	bhari						
8	☐ Agricultural waste	bhari						
9	☐ Animal dung	tokari						0
95	☐ Other (specify)							

7. If you use any of the following fuels for cooking, for how many years have you been using it?

S NO	Fuel used for cooking	Years
1	Electricity	
2	Solar power	
3	LPG	
3	LPG	
4	Biogas	
5	Kerosene	

8. If you have **biogas,** what is the size of the biogas plant? ______________________m^3
   How much subsidy did you get for biogas? Rs______________

9. If you do not have a biogas plant, are you planning to construct it? ☐ Yes ☐ No

10. Are loan facilities readily available in case you need them? ☐ Yes ☐ No

11. If you use **fuelwood** do you or a member of your family collect it? ☐ Yes ☐ No (>> 13)

12. How long does it take to collect fuelwood from the forest?
    ☐ One bhari, or ☐ one cart takes __________ hours

13. How much fuel do you use for cooking in summer and winter seasons?

S.NO	Fuel	Summer	Winter	Unit and Period (√ appropriate boxes)	
1	Electricity			☐Units ☐Rs.	☐Units ☐Rs. ☐per month
2	LPG			One 14.2 kg cylinder enough for ?? days	
3	Kerosene			☐Liter	☐per day, ☐per week, ☐per month
4	Coal			☐kg,☐bag	☐per day, ☐per week, ☐per month
5	Fuelwood			☐kg,☐bhari	☐per day, ☐per week, ☐per month
6	Agricultural waste			☐kg,☐bhari	☐per day, ☐per week, ☐per month
7	Animal dung cake			☐kg,☐tokari	☐per day, ☐per week, ☐per month
8	Mud chula (traditional)				

14. How many *chulas* do you use?

S No	Type of chula	No	If you have it				Used for cooking (write 'C') or for heating (write 'H')
			How much did you pay for each chula ? *(Rs/chula)*	Year of purchase?	How much will it cost now if you sell? *(Rs/chula)*	How long will it work? (Expected life in years)	
1	Gas stove (for LPG or biogas)						
2	Kerosene stove						
3	Improved chula (for fuelwood)						
4	Coal/briquettes chula						
5	Rice cooker						
6	Electric heater						
7	Iron tripod/three stone						
8	Mud chula (traditional)						

15. Do you have an improved *chula*? ☐ Yes ☐ No (>> 20)

16. If you have an improved *chula*, how did you get it?
constructed by mistry, constructed yourself, purchased from market

17. Do you like the improved *chula*? ☐ Yes ☐ No (>> 19)

18. What are your reasons for liking it? (answers may be multiple)
☐ fuel efficiency ☐ easy to handle ☐ utensils remain clean
☐ less smoke ☐ any other (specify)————————————(>>21)

19. What are the reasons for not liking the improved *chula*? (answers may be multiple)
☐ Difficult to handle ☐ takes longer time for cooking
☐ does not fit the pots ☐ pots become dirty,
☐ more smoke ☐ not enough heat available for space heating
☐ location of stove needs to be changed
☐ danger of termites damaging the ceiling wood in the absence of smoke
☐ any other (specify) ————————————————————-(>> 21)

20. If you do not have an improved *chula*, do you want to purchase or construct one? ☐ Yes

☐ No If no, why?

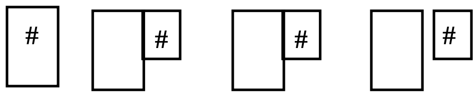
☐ not available	☐ costly
☐ difficult to handle	☐ takes longer time for cooking
☐ does not fit the pots	☐ pots become dirty
☐ more smoke	☐ any other (specify)————————————

21. Do you want to switch to new fuels for cooking? ☐ Yes ☐ No (>> 22)
If yes, which fuel would you like?
☐ Fuelwood ☐ Coal ☐ Kerosene ☐ Biogas ☐ LPG, ☐ Electricity

22. How many meals do you cook per day? ☐1 ☐2 ☐3 ☐4

23. How long does it take to prepare each meal? ☐30 minutes ☐1 hour ☐2 hours ☐3 hours

24. Where is the kitchen (#) located?



25. What is the dimension of the kitchen (or the room where you cook)?
Length ...., breadth .... height.......... ☐feet ☐hat ☐yard ☐meter

26. What is the material of the roof/ceiling of your kitchen?

☐thatch ☐slate ☐corrugated sheets ☐wood ☐mud ☐cement ☐concrete

27. Are there walls on all the sides of your kitchen? ☐ Yes ☐ No

28. How is the kitchen ventilated?

☐window opening (hole) or raised roof ☐Chimney/exhaust fan ☐non-of the above

☐Others (specify ——————

29. Have you made any improvements to your kitchen in the last year to reduce smoke in the room?

☐ Yes ☐ No (>>30)

If yes, what improvements did you make? (Answers may be multiple)

	Improvement	How much does it cost?
1	☐ Fitted exhaust fan	
2	☐ Enlarged eves space	
3	☐ Fitted window or ventilation	
4	☐ Fitted hood/ flue/ chimney	
5	☐ Constructed partition wall to separate kitchen and living areas	
6	☐ Constructed separate kitchen	
95	☐ Any other (specify)	

30. Do you want to redesign your kitchen to reduce smoke? ☐ Yes ☐ No (>>31)

If yes, what do you want to change? (Answers may be multiple)

1 ☐ Fit exhaust fan
2 ☐ Enlarge eves space
3 ☐ Fit window or ventilation
4 ☐ Fit hood/ flue/ chimney
5 ☐ Construct partition wall to separate kitchen and living areas
6 ☐ Construct separate kitchen
95 ☐ Any other (specify)

If you do not use firewood, agricultural waste, dung cake, coal, briquette or kerosene (>> 40).

31. Do you use kerosene while lighting the firewood, dung cake or coal for cooking?
☐ Yes ☐ No

32. Do you break firewood to small pieces before burning? ☐ Yes ☐ No

33. Do you dry the firewood before burning? ☐ Yes ☐ No

34. Do you keep your children away from the kitchen while cooking? ☐ Yes ☐ No

35. Do you keep your children away while lighting or putting off the fire? ☐ Yes ☐ No

36. Do you put off the fire after completion of the cooking? ☐ Yes ☐ No

37. If you do anything else to avert smoke, please specify. ....

38. How many people are there in your household? .... persons (including servants, if any)

39. Education and occupation of family members:

Mem ber Code	Relation*	Gender Male=1 Female=2	Age	Education**[16]	Main occupation ***[17]	Subsidiary occupations ***	For how many months[18] does he/ she stay at home?
1	Self						
2							
3							
4							
5							
6							
7							
8							
9							
10							

[16] Education is counted only for those who are above the age of 5 years.
[17] Occupation only for those who are between the age of 16 to 60 years.
[18] In the last year.

* Respondent=1, Husband/wife=2, Son/daughter=3, Grand child= 4, Father/mother=5, Brother sister=6, Nephew/niece=7, Son/daughter-in-law=8, Brother/sister-in-law=9, Father/mother-in=law=10, Other family relatives=11, Servants/servant's relative=12, other persons not related=13.
** Illiterate =0, Class = years, SLC = 11, Intermediate =13, Graduate =15, Post graduate =17, Ph. D. =20.
*** Agriculture = 1, Service =2, Self employed =3, Housewife =4, Student = 5, Working abroad =6, unemployed =7.

40. Who cooks food[19] in your household?........................... (use member code from question 4)

41. Did any member of the household (above 5 years of age) suffer from the following symptoms last year ? (√ for yes), if No (>>43)
[Or medically identified case of bronchitis (a+b), asthma (c+d) and eye irritation (e+f)]

Member Code*	Cough for most days for 3 months each year	Bring up phlegm for 3 months each year	Stop for breath when walking at own space	Woken at night by attack of shortness of breath	Redness in eyes	Watery eyes	Smoking habit?
	a	B	C	D	e	f	

*Copy the member codes from the question No 40.

42. Costs of Symptoms of Bronchitis, Asthma and Eye Irritation during Last Year

Member code	No of visit to doctor	Average cost per visit						Work days lost on farm due to illness (No of Days)	Dietary expenses resulting from illness (NRs)	Time spent by family member(s) (Hours = H, Days = D)
		Medicine Costs (NRs)	Laboratory Costs (X-ray, Blood etc examination) (NRs)	Hospital-/Doctor Fees (NRs)	Travel Costs to and from for treatments (NRs)	Time spent on traveling (Hours)	Time spent on health post or hospital (Hours =H, Days = D)			

*Copy the member codes from the question No 40.

43. Did any member of the household (above 5 years of age) suffer from the following symptom during the last **5 years**? (√ for yes)
[Or medically identified case of bronchitis (a+b), asthma (c+d) and eye irritation (e+f)]

Cough for most days for 3 months each year	Bring up phlegm for 3 months each year	Stop for breath when walking at own space	Woken at night by attack of shortness of breath	Redness in eyes	Watery eyes
A	b	C	d	e	f

[19] Write member code. If more than one person involved in cooking, write member codes of all involved in decreasing order of involvement.

44. Did any children (5 years and below) suffer from the following symptom during last year? (Ö for yes), if No (>>46).
[Or medically identified case of Acute Respiratory Infection (h+i+j) and pneumonia (k+l)]

Member Code*	Child stopped feeding well	Child abnormally sleepy or difficult to awake	Fever or low body temperature	Localized chest pain	Cough at first dry and painful, later productive and tenacious with rusty sputum or occasionally frank blood stained
	h	i	J	K	l

45. Costs of the symptoms of Acute Respiratory Infection and pneumonia during last year (Aged 5 years and less)

Member code	No of visits							Work days lost on farm due to illness (No of Days)	Dietary expenses resulting from illness (NRs)	Time spent by family member(s) (Hours = H, Days = D)
		Medicine Costs (NRs)	Laboratory Costs (X-ray, Blood etc examination) (NRs)	Hospital-/Doctor Fees (NRs)	Travel Costs to and from for treatments (NRs)	Time spent on traveling (Hours)	Time spent on health post or hospital (Hours =H, Days = D)			

*Copy the member codes from the question No 40.

46. Did any children (5 years and below) suffer from the following symptom during the last 5 years? (√ for yes) [Or medically identified case of Acute Respiratory Infection (h+i+j) and pneumonia (k+l)]

Child stopped feeding well	Child abnormally sleepy or difficult to awake	Fever or low body temperature	Localized chest pain	Cough at first dry and painful, later productive and tenacious with rusty sputum or occasionally frank blood stained
H	I	J	k	L

47. How long does it take to reach the nearest of the following facilities (one way)?

	Facility	Hours	Minutes
1	Hospital or health post		
2	Medical shop/dispensary		
3	Market center		
4	Road		

48. Does your household have any of the following items?
☐ Car/jeep/bus/truck etc ☐ Motor cycle ☐ Cycle ☐ Telephone ☐ Refrigerator
☐ TV, ☐ Radio ☐ Watch

49. May I ask you about your household income (non-agricultural)?

Average cost per visit

	Source	Total income NRs	Period (appropriate box)
1	Salary (of members residing at home)		☐per month ☐per year
2	Income from family members working abroad or city*		☐per month ☐per year
3	Contract/piece rate work		☐per month ☐per year
4	Daily wage (including the value of what is received in kind)		☐per month ☐per year
5	Pension		☐per month ☐per year
6	Self employment		☐per month ☐per year
7	Rent of building/shutter/ equipment/bullock, etc.		☐per month ☐per year
8	Interest/dividends, etc.		☐per month ☐per year
9	Any other (specify)		

* Take into account only the part of income received at home.

50. Do you have agricultural land? ☐ Yes ☐ No (>> 53)
If yes, how much land do you have? Khet.........Bari....... ☐Ropani, ☐Bigha ☐Katha ☐Hall

51. Do you purchase chemical fertilizers? ☐ Yes ☐ No (>> 52)
If yes, how much during last year?

	Fertilizer	Quantity	Unit (√appropriate box)
1	Urea		☐kg, ☐bag
2	DAP		☐kg, ☐bag
3	Potash		☐kg, ☐bag
4	Complex		☐kg, ☐bag
5	Others (specify)		☐kg, ☐bag

52. How much was your crop productions last year?

		Quantity	Unit (√ appropriate box)
1	Paddy		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
2	Wheat		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
3	Maize		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees ☐bhari
4	Barley		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
5	Potatoes		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
6	Mustard		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
7	Vegetables		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
8	Fruits		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
9	Ginger		☐quintal, ☐muri, ☐kacha mound, ☐pucka mound, ☐Rupees
10	Any other, specify		

53. How many cattle and buffaloes do you have?

		Adult
1	Cattle	
2	Buffalo	

54. How much were your livestock and poultry productions?

		Quantity	Unit (appropriate box)	Period (appropriate box)
1	Goat		☐ number, ☐ Rupees	☐ per year
2	Sheep		☐ number, ☐ Rupees	☐ per year
3	Pigs		☐ number, ☐ Rupees	☐ per year
4	Poultry		☐ number, ☐ Rupees	☐ per week, ☐ per month ☐ per year
5	Milk		☐ liter, ☐ mana, ☐ kg, ☐ Rupees	☐ per day, ☐ per month ☐ per year
6	Egg		☐ number, ☐ Rupees	☐ per day, ☐ per month, ☐ per year-
7	Honey		☐ liter, ☐ mana, ☐ kg, ☐ Rupees	☐ per year
8	Silk		☐ kg, ☐ Rupees	☐ per year
9	Any other, specify			

Annex II: Definitions and Expected Signs of the variables used in PM_{10} Production Function

	Variable	Definitions	Expected sign
1	Fuelwood	A dummy is used for use of fuelwood for cooking	+
2	Biogas	Use of biogas by sample household	-
3	ICS	Improved Cooking Stove (ICS) taken as a dummy	-
4	Kitchen area	Area of the kitchen in square feet	-
5	Ventilation	Any type of ventilation in the kitchen	-
6	Cooking hours	Average daily hours used for cooking, in terms of the time that the stove runs	+
7	PM10 level in the kitchen	Monitored level of particulate matter of size 10 micron or less (PM10), taken as weighted average of cooking and non-cooking hours in 24 hours in µg/m3	Dependent

Annex III: Test of Multicollinearity and Heteroskedasticity

	Variable	Szroeter's test for homoskedasticity				Variance inflation factor (VIF) for multicollinearity
		x^2	degree of freedom	Unadjusted p value	Variance	
1	Average PM10	0.82	1	0.366	Constant	
2	Biogas	2.40	1	0.122	Constant	1.31
3	Kitchen area	0.03	1	0.873	Constant	1.17
4	ICS	0.70	1	0.402	Constant	1.17
5	Cooking hours	1.60	1	0.206	Constant	1.16
6	Fuelwood	4.79	1	0.029	Monotonic	1.09
7	Ventilation	0.06	1	0.814	Constant	1.06
8	Mean VIF					1.16

Annex IV: Zero-order Correlation between the Explanatory Variables for PM_{10}

		Fuelwood	Biogas	ICS	Kitchen area	Ventilation	Cooking hours
1	Fuelwood	1.000					
2	Biogas	**-0.085****	1.000				
3	ICS	0.043	-0.058	1.000			
4	Kitchen area	0.023	0.066	**-0.080****	1.000		
5	Ventilation	-0.030	**0.103****	0.039	0.064	1.000	
6	Cooking hours	**-0.002***	0.016	-0.034	**0.080***	0.050	1.000

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex V: Descriptive statistics of Distance from the Household Variables

	Distance to (minutes taken)	N	Mean	Standard Deviation	Minimum	Maximum
1	Hospital	600	42.745	21.860	2	360
2	Medical	600	38.665	21.310	1	60
3	Market	600	41.140	21.162	1	60
4	Road	600	28.330	22.733	1	90

Source: Household survey, 2005.

Annex VI: Zero-order Correlation between Distance from the Household Variables

	N=600	Hospital	Medical	Market	Road
1	Hospital	1.000			
2	Medical	0.282***	1.000		
3	Market	0.208***	0.798***	1.000	
4	Road	0.323***	0.615***	0.598***	1.000

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex VII: Zero-order Correlation of IV Candidates with the Health Variables to Detect Their Validity

			For grown up people (n=2739)	For under five children (n=301)	Validity of IV#
		Chronic bronchitis	Asthma	ARI	
1	**Distance to the market**	-0.022	0.030	-0.057	Valid
2	Distance to the medical	0.001	0.044**	0.006	Moderately valid
3	**Sex Ratio**	0.007	0.001	0.024	Valid
4	Price of fuelwood	0.039**	0.029	-0.043	Moderately valid
5	**Access to credit**	-0.031	-0.026	0.002	Valid
6	**Price of LPG**	0.042**	0.011	0.067	Moderately valid
7	Price of biogas	0.039**	0.030	-0.021	Moderately valid
8	Price of ICS	-0.013	-0.026	0.029	Valid
9	Subsidy on biogas	0.058***	0.042**	-0.043	
10	**Year of use of biogas**	0.001	0.001	-0.119**	Moderately valid
11	Irrigated land	-0.013	0.005	-0.140**	
12	Non-irrigated land	0.070***	0.019	-0.067	Moderately valid
13	Total land	0.014	0.011	-0.157***	
14	Total land square	0.021	0.030	-0.115**	Moderately valid
15	Rice production	-0.039**	-0.034*	-0.155***	
16	Rice production squared	-0.017	-0.017	-0.126**	
17	Maize production	-0.051***	-0.041**	-0.041	
18	**Maize production squared**	-0.027	-0.023	-0.094	Valid
19	Cereal grain production	-0.047***	-0.041**	-0.151***	
20	Cereal grain production squared	-0.028	-0.027	-0.131**	
21	Income from crops	-0.032*	-0.039**	-0.067	
22	Agricultural income	-0.037**	-0.025	-0.040	Moderately valid
23	Salary	-0.034*	-0.033**	-0.178***	
24	Non-agricultural income	-0.033*	-0.008	-0.136**	
25	Total income	-0.045**	-0.018	-0.127**	
26	Total income squared	-0.005	0.015	-0.185***	
27	**Non-agriculture income as % of total income**	-0.026	-0.018	-0.008	Valid
28	**Fridge**	-0.011	-0.003	0.018	Valid
29	**TV**	-0.065***	-0.044**	-0.137**	
30	Radio	-0.036*	0.003	-0.021	Moderately valid
31	Vehicle	-0.024	0.000	-0.080	Valid

#Note: Instrument with low level of correlation (arbitrarily up to 0.12) with only one health outcome is regarded as moderately valid.

Note: '**Bold**' variables are used as instruments.

Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex VIII: Zero-order Correlation of IV Candidates with the Endogenous Variables to Find Their Strengths

	Candidates	For grown up people (n=2739)				For under five children (n=301)				Strength
		ICS plus	Biogas	LPG	Wood	ICS plus	Biogas	LPG	Wood	
1	**Distance to the market**	-0.055***	-0.135***	-0.135***	-0.166***	-0.095*	-0.139**	-0.136**	-0.310***	Strong
2	Distance to the medical	-0.022	-0.179***	-0.181***	-0.220***	-0.142***	-0.174***	-0.246***	-0.292***	Mild
3	**Sex Ratio**	-0.075***	0.000	-0.071***	0.035*	-0.121**	-0.040	-0.057	0.123**	Mild
4	Price of fuelwood	0.107***	0.135***	-0.030	-0.018	0.142***	0.112**	0.013	-0.091	Mild
5	**Access to credit**	0.190***	0.347***	0.141***	0.029	0.281***	0.366***	0.213***	0.097*	Strong
6	**Price of LPG**	0.218***	0.018	-0.097***	0.016	0.311***	-0.032	-0.123**	-0.060	Strong
7	Price of biogas	0.014	0.049***	-0.018	0.005	0.025	-0.109*	-0.108*	-0.009	
8	Price of ICS	-0.034*	0.047***	0.041***	0.039**	0.013	-0.022	-0.038	0.062	
9	Subsidy on biogas	0.301***	0.088***	-0.079***	-0.009	0.363***	0.053	-0.015	-0.046	Strong
10	**Year of use of biogas**	-0.105***	0.807***	-0.101***	-0.082***	-0.049	0.747***	-0.081	-0.068	Strong
11	Irrigated land	-0.074***	0.197***	0.086***	-0.120***	0.009	0.227***	0.150***	-0.181***	Mild
12	Non-irrigated land	0.308***	0.131***	-0.007	0.023	0.328***	0.183***	-0.084	0.062	Strong
13	Total land	0.044**	0.234***	0.079***	-0.105***	0.116**	0.278***	0.116**	-0.154***	Mild
14	Total land square	-0.009	0.151***	0.039**	-0.099***	0.100*	0.191***	0.104*	-0.201***	Mild
15	Rice production	-0.049***	0.205***	0.167***	-0.097***	0.033	0.292***	0.243***	-0.106*	Mild
16	Rice production squared	-0.010	0.120***	0.156***	-0.117***	0.070	0.170***	0.263***	-0.198***	Mild
17	Maize production	-0.002	0.127***	0.103***	-0.045**	-0.078	0.309***	0.043	0.009	Strong
18	**Maize production squared**	0.045**	0.058***	0.070***	-0.053***	-0.093	0.243***	-0.019	-0.052	Mild
19	Cereal grain production	-0.026	0.189***	0.165***	-0.077***	0.004	0.339***	0.210***	-0.071	Strong
20	Cereal grain production squared	0.029	0.113***	0.154***	-0.080***	0.050	0.257***	0.259***	-0.168***	Mild
21	Income from crops	0.072***	0.239***	0.120***	-0.003	0.092	0.316***	0.162***	-0.047	Strong
22	Agricultural income	0.022	0.228***	0.080***	-0.013	0.052	0.370***	0.123**	-0.068	Strong
23	Salary	0.038**	0.078***	0.190***	-0.061***	0.093	0.093	0.141**	-0.066	Mild
24	Non-agricultural income	0.159***	0.062***	0.256***	0.007	0.135**	0.275***	0.342***	-0.067	Strong
25	Total income	0.144***	0.154***	0.252***	0.000	0.131**	0.369***	0.328***	-0.081	Strong
26	Total income squared	0.087***	0.050***	0.157***	-0.018	0.073	0.342***	0.283***	-0.136**	Strong
27	**Non-agriculture income as % of total income**	0.156***	-0.026	0.220***	0.027	0.082	-0.037	0.193***	-0.011	Mild
28	**Fridge**	0.149***	0.120***	0.377***	0.013	0.272***	0.094*	0.609***	0.115**	Strong
29	**TV**	-0.013	0.201***	0.227***	0.036*	0.156***	0.214***	0.328***	0.067	Strong
30	Radio	0.073***	0.005	0.103***	0.089***	0.176***	0.139**	0.131**	0.049	Mild
31	Vehicle	0.013	0.129***	0.086***	-0.001	0.068	0.130**	0.271***	-0.014	Mild

Notes: '**Bold**' variables are used as instruments. * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex IX: Effects of Fuel Consumption and *Chula* on Chronic Bronchitis (age >10 years) - Without IV

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	Improved cook stoves+	-0.103	-0.006	0.007	0.437	-0.019	0.006
2	Biogas+	-0.049	-0.003	0.006	0.313	-0.014	0.008
3	LPG	-0.002	-0.0001	0.000	12.112	0.000	0.000
4	Wood	-0.023***	-0.001***	0.001	12.642	-0.002	0.000
5	Age	0.031***	0.002***	0.000	33.417	0.002	0.002
6	Female+	0.525***	0.032***	0.006	0.495	0.020	0.044
7	Hill+	0.426***	0.026***	0.007	0.497	0.013	0.038
8	Constant	-3.100***		Log likelihood	LR chi2(7)	248.59	
9	Observed P		0.055	n=2739	Prob > chi2	0.000	
10	Predicted P		0.025	(at x-bar)	Pseudo R2	0.214	

(+) dF/dx is for discrete change of dummy variable from 0 to 1
Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex X: Effects of Fuel Consumption and *Chula* on Asthma (age>10 years)– Without IV

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	Improved cook stoves+	-0.111	-0.005	0.005	0.437	-0.015	0.006
2	Biogas+	-0.204*	-0.008*	0.004	0.313	-0.016	0.000
3	LPG	-0.002	-0.0001	0.000	12.112	0.000	0.000
4	Wood	-0.030***	-0.001***	0.000	12.642	-0.002	0.000
5	Age	0.024***	0.001***	0.000	33.417	0.001	0.001
6	Female+	0.676***	0.030***	0.005	0.495	0.019	0.041
7	Hill+	0.195*	0.008*	0.005	0.497	-0.002	0.018
8	Constant	-2.838***		Log likelihood	LR chi2(7)	133.20	
9	Observed P		0.034	n = 2739	Prob > chi2	0.000	
10	Predicted P		0.017	(at x-bar)	Pseudo R2	0.164	

(+) dF/dx is for discrete change of dummy variable from 0 to 1
Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex XI: Effects of Fuel Consumption and *Chula* on ARI among the Children (age <=5 years) – Without IV

	Explanatory variables	Coefficient	dF/dx	Standard Error	x-bar	95% Confidence Interval	
1	Improved cook stoves+	0.204	0.072	0.080	0.352	-0.084	0.228
2	Biogas+	-0.369**	-0.137	0.067	0.246	-0.268	-0.006
3	LPG	-0.007**	-0.002	0.001	13.293	-0.005	0.000
4	Wood	0.023**	0.008	0.004	12.658	0.000	0.016
5	Age	-0.127**	-0.045	0.020	3.199	-0.084	-0.006
6	Female+	-0.207	-0.074	0.055	0.518	-0.181	0.034
7	Hill+	-0.178	-0.064	0.067	0.465	-0.195	0.067
8	Constant	0.877***		Log likelihood	LR chi2(7)	21.23	
9	Observed P		0.671	n = 301	Prob > chi2	0.003	
10	Predicted P		0.679	(at x-bar)	Pseudo R2	0.056	

(+) dF/dx is for discrete change of dummy variable from 0 to 1
Note: * significant at 10 percent level, ** significant at 5 percent level, and *** at 1 percent level.

Annex XII: Costs of Illnesses

	Cost headings	Unit	Chronic bronchitis	Asthma	ARI
1	Medicine Costs	Rs	2,107.5	1,706.0	3,604.2
2	Laboratory Costs (X-ray, cough test etc.)	Rs	64.3	57.0	173.4
3	Hospital/Doctor Fees	Rs	104.1	92.0	224.9
4	Travel Costs to and from for the treatments	Rs	43.9	41.9	88.1
5	Additional dietary expenses resulting from illness	Rs	19.0	18.0	31.4
A	**Total cash expenses**	**Rs**	**2,338.8**	**1,914.9**	**4,122**
1	Time spent on traveling	hour	1.7	1.4	6.6
2	Time spent on health post or hospital	hour	21.1	20.1	8.9
3	Work hours lost due to illness	hour	12.1	9.6	0.0
4	Time spent by care takers	hour	7.3	5.6	26.4
5	Total time lost due to illness	hour	42.2	36.7	31.3
B	**Opportunity cost of time (@ 45% of wage rate Rs 100/8 hours)**	**Rs**	**237.38**	**206.46**	**176.04**
	Total costs of illness (A+B)	**Rs**	**2,576.18**	**2,121.36**	**4,298.04**

Source: Household survey 2005